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(71) Applicant: **CANON KABUSHIKI KAISHA**
Tokyo (JP)

(72) Inventors:
• **Iwanaga, Takehiko**
Ohta-ku, Tokyo (JP)

• **Yamada, Yuichi**
Ohta-ku, Tokyo (JP)
• **Uzawa, Shigeyuki**
Ohta-ku, Tokyo (JP)

(74) Representative:
Beresford, Keith Denis Lewis et al
BERESFORD & Co.
2-5 Warwick Court
High Holborn
London WC1R 5DJ (GB)

(54) **Surface position detecting method and scanning exposure method using the same**

(57) A surface position detecting method for detecting a surface position of a surface to be examined, having surface height irregularity, while relatively scanning the surface, is disclosed. The method includes detecting characteristic data related to a surface state at plural

measurement positions on the surface, while relatively scanning the surface, and processing the detected characteristic data related to the measurement positions to determine a measurement position for measurement of the surface position in a subsequent surface position detecting process.

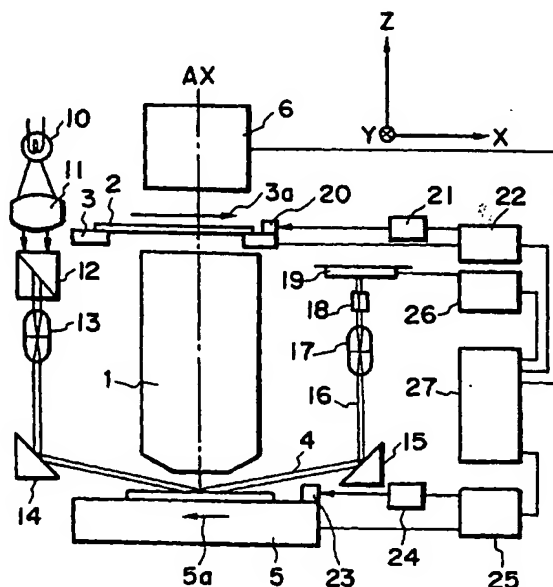


FIG. 1

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D scription

This invention relates to a surface position detecting method for detecting level (height) or tilt, for example, of a surface of a planar object such as a wafer, for example. More particularly, the invention is concerned with a surface position detecting method usable in a slit-scan type exposure apparatus, for successively detecting position or tilt, for example, of a surface of a wafer with respect to the direction of an optical axis of a projection optical system. In another aspect, the invention is concerned with a surface position setting method for an exposure apparatus, for example, and/or with a scanning exposure apparatus using such surface position detecting/setting method.

The size of memory chips is recently increasing due to the difference between the tendency of cell size or resolvable line width of an exposure apparatus and the tendency of enlargement of memory capacity. As an example, for the first generation of 256M memories, the chip size is about 14 x 25 (mm).

For such chip size, with an exposure region of 31 mm diameter of a reduction projection exposure apparatus (stepper) currently used as an exposure apparatus for a critical layer, only one chip can be exposed with one exposure operation. Thus, the throughput is very low. An exposure apparatus capable of exposure with a larger area is therefore desirable.

As for large field size exposure apparatus, there are reflection projection exposure apparatuses which are widely used as a semiconductor device exposure apparatus for use for rough layer with which a high throughput is required, or as an exposure apparatus for manufacture of large-field liquid crystal display devices such as monitors. Exposure apparatuses of this category comprise a slit scan type exposure apparatus which is based on mask-to-wafer relative scan wherein a mask is linearly scanned with illumination light of arcuate slit-like shape, and wherein a pattern of the mask is printed in a single exposure on to a wafer by means of a concentric reflection mirror optical system.

As regards the focusing of a mask image in these exposure apparatuses, in order to continuously keep the exposure surface of a photosensitive substrate (such as a wafer or a glass plate which is coated with a photoresist, for example) in registration with a best imaging plane of a projection optical system, height (level) measurement and autofocus or auto-leveling correction drive are successively performed during the scan exposure process.

As for surface position detecting mechanism in such apparatuses, there are a method in which an oblique light projection optical system is used to project a light beam on to a wafer surface obliquely from the above and in which reflection light from the photosensitive substrate is detected as a positional deviation upon a sensor, and a method in which a gap sensor such as an air microsensor or an electrostatic capacity sensor

is used. In these methods, from plural values of measured heights obtained during the scan, correction drive amount for height and tilt as a measurement position passes an exposure slit region is calculated and, based on this, correction is made.

If, in currently used slit scan type exposure apparatuses, only the projection system thereof is modified to provide a resolving power that can meet the capacity of 256M or larger, the following problems will be produced.

Namely, with enlargement of numerical aperture (N.A.) of a reduction projection system to meet miniaturization of circuit pattern, the tolerable depth of focus in the circuit pattern transfer process becomes narrower and narrower. With exposure apparatuses currently used for rough processes, a tolerable depth of focus of not less than 5 microns is assured. Therefore, a measurement error which may be included in measured values, successively measured during the scan exposure process, or the effect of a surface level difference within a chip may be disregarded. However, in consideration of the capability to 256M, the tolerable depth is 1 micron or less. Thus, a measurement error in measured values or the effect of surface level difference within a chip could not be disregarded.

Further, in the exposure sequence according to conventional stepper type process, after completion of focus correction at the exposure position the sequence goes on uninterruptedly (in series) to the start of exposure. Thus, any dispersion of focus measurement time does not have an influence on the precision. With the exposure sequence according to the slit scan type process, however, the exposure process is being done even during focus measurement. That is, both of them are performed simultaneously, in parallel processing. Therefore, any dispersion of focus measurement time will apply an influence, as a time delay component, upon the feedback loop of the focus correction system as a whole, including the driving system and, as a result, it may cause degradation of focus correction precision.

Moreover, there is a problem of surface level irregularity on the chip surface, which is a difficulty to be solved to accomplish high precision focus detection. As an approach from the process side, in relation to the insufficiency of tolerable depth of focus, those methods which uses a recess array or CMP to provide a surface step structure of low level difference have been developed. Even with those methods, there still remains a surface level difference of about 0.5 micron. Particularly with regard to a peripheral circuit portion or a scribe line portion, a step-like surface level difference structure remains. At such structure portion, even after application of a resist material, there remains a slow inclination on the surface and, as a result of it, the following problems are produced.

Namely, when a surface having such slow inclination is to be detected by use of an oblique light projection type height detection system, there is a possibility that the intensity of detection light becomes extraordinarily

low. This is because in this detection system the detection light path is limited so as to detect only reflection light having substantially the same angle as the incidence angle, to thereby avoid reception of noise light. If the diameter of a light receiving stop at the detection light path side is enlarged in an attempt to increase the intensity of detection light from the inclined surface portion, the intensity of noise light also increases which, as a consequence, enlarges the measurement error. It is therefore undesirable to enlarge the diameter of the light receiving stop immoderately.

When the inclined surface region of the portion to be measured is small as compared with the size of the detection beam, the shape of a detection waveform may be deformed asymmetrically which in turn may result in a large measurement error. Such phenomenon may easily appear particularly in relation to a scribe line portion, as compared with the chip region, with respect to which no process control is made. Also, there is small reproducibility within the wafer. It is therefore difficult to correct the same by use of offset. If under such situation the focus measurement in slit scan is done, there is a possibility that the focus detection is disabled in the course of the scan exposure such that the scan exposure is interrupted. Alternatively, a large defocus may be created to cause production of defective chips.

Measured values which may cause a problem may be excluded during the measurement in the scan exposure. However, executing such processing within a limited measurement time may cause complicatedness of the system. Even such a system is arranged, variation of measurement time or decrease of throughput may cause degradation of focus precision. Namely, in a system in which the focus correction is to be made in real time fashion and the exposure process is to be made simultaneously therewith, what is most important is smooth operational association between units. If the balance is destroyed, there will occur various problems such as shift of offset correction timing or phase shift of delay compensation in the correction system and, finally, a resolution performance as designed will not be provided.

On the other hand, in the autofocusing or auto-leveling in a slit scan type exposure apparatus, a wafer moves during the exposure process and, for this reason, there is a possibility that, in accordance with the rate determination by the response speed of a focus plane detection system and of a wafer stage height (wafer height) driving system, a following-up error (i.e., focus error) is created.

This will be explained in detail, in conjunction with Figure 10. In Figure 10(a), it is assumed that a pattern of a reticle is going to be printed on an exposure region C on the surface of a wafer 41 which is being moved in a direction of an arrow X. If height measuring means 40A is provided at a position of the center A of the exposure region C and the wafer stage drive is made on the basis of a measured value therefrom, because of

the response delay described above, the wafer surface can not follow the focus plane. In consideration of this, usually in scan type exposure apparatuses the height measuring means is provided at a position different from the point A on the exposure region C and the height of the wafer surface is measured beforehand. As that position comes to the exposure position, the wafer height is adjusted into the exposure plane. In Figure 10(a), height measuring means 40B is provided at a position before the exposure region center A with respect to the wafer movement direction, which position is spaced by a distance d from the center A. At the moment as the point A comes to the position just below the height measuring means 40B, the height of the wafer surface at the point A is measured. Then, at the moment as the point A comes to the position below the exposure region C, the wafer height is adjusted to the exposure plane. The sampling interval in this case corresponds to the time period ($t_s = d/s$ where s is the wafer scan speed) by which the wafer moves through the distance d.

Figure 10(b) shows the relation among a wafer surface 41, a wafer height 42 as moved, and a difference between the wafer surface 41 and the wafer height 42 as moved, that is, the focus error 43, in a case where the response speeds of the detection system and the driving system are slow as compared with the wafer scan speed (sampling interval t_s). Due to such response delay, there is a large focus error.

Figure 10(c) shows the relation among a wafer surface 41, a wafer height 44 as moved, and a focus error 45 in a case where the response speeds of the detection system and the driving system are higher as compared with the wafer scan speed. Since the response speed is higher than the measurement interval, there is a larger focus error between measurement points.

Figure 10(d) shows an example where the sampling interval is shortened so as to avoid this. The sampling interval is made to be equal to the time in which the wafer moves through a distance d/5. Also, there is shown the relation among a wafer surface 41, a wafer height 46 as moved, and a focus error 47. The focus error is small, and good following-up is assured.

However, shortening the sampling interval will cause the following problems. As a result of flattening through a CMP method, for example, to the cell portion and the peripheral circuit portion, within the wafer surface there may be a surface level difference of only about 1 micron. However, when a wafer outer peripheral portion is to be exposed and the drive is to be made from the outside to the inside of the wafer, the wafer height has to be changed by a few tens microns within a time period in which the wafer moves through a distance d of the spacing of sensors. Thus, it is not possible to determine the sensor spacing d on the basis of only the surface level difference within the wafer. Further, when the sampling interval is to be reduced and if an accumulation type detecting means such as CCD, for example, is used, a finite accumulation time is necessary and it

defines the rat determination. Also, the quantity of traffic flowing through the data bus of the measurement system increases. As a result, the control system becomes complicated and expensive.

The above-described points are problems of the wafer height measuring system. In addition to them, there is a problem of abbe error which may be created by inclination of the surface of a bar mirror of a laser interferometer when the wafer height is changed. In conventional apparatuses in which a wafer is exposed while it is held stationary, such abbe error is corrected by moving the stage in X and Y directions by an amount effective to correct other components (X and Y components) created by the wafer height driving. Moving the X-Y stage takes a longer time until the target position is reached as compared with a case where drive is made in the wafer height direction, since the mass of the components to be driven is larger. However, in this type of apparatuses, the exposure process starts after the X-Y stage reaches the target position. Thus, there is no possibility that the abbe correction has an influence upon the printing linewidth precision or exposure position precision, for example.

In scan type exposure apparatuses, however, since the abbe correction has to be done during scan of the stage, the following problem will arise. When a reticle and a wafer are scanned for exposure by use of a scan type exposure apparatus, the wafer stage and the reticle stage have a large mass as described and, therefore, fine control of them is not easy to achieve. Usually, drive pattern for them is based on a trapezoidal profile drive in which a constant-speed portion of the drive profile is used for the printing process. If abbe correction drive is added to this, the target value for the constant-speed profile portion during the printing process has to be rewritten. If the amount of changing the target value is large, vibration may be created in relation to the stage drive which vibration in turn may result in degradation of linewidth precision of the printing process. Such problem will be more notable with enlargement of the wafer size to 10-inch or 12-inch wafer and with corresponding increases in mass of the stage.

In accordance with an aspect of the present invention, there is provided a surface position detecting method for detecting a surface position of a surface to be examined, having surface height irregularity, while relatively scanning the surface, said method comprising the steps of: detecting characteristic data related to a surface state at plural measurement positions on the surface, while relatively scanning the surface; and processing the detected characteristic data related to the measurement positions to determine a measurement position for measurement of the surface position in a subsequent surface position detecting process.

In said characteristic data detection, surface position data and a characteristic amount which represents a shape of a detection signal may be detected.

In accordance with another aspect of the present

invention, there is provided a scanning exposure method for printing a pattern of an original on to a substrate while relatively scanning the original and the substrate, said method comprising the steps of: detecting characteristic data related to a surface state at plural measurement positions on the surface of the substrate, while relatively scanning the substrate surface; and processing the detected characteristic data related to the measurement positions to determine a measurement position for measurement of the surface position to the substrate surface in surface position detection during a scanning exposure process.

In said characteristic data detection, surface position data and a characteristic amount which represents a shape of a detection signal may be detected.

Said characteristic data detection may include detecting the characteristic data while performing the relative scan at a scan speed lower than the scan speed during the scan exposure process.

Said determination of measurement position may include determination of a measurement position for measurement of the surface position of the substrate surface in accordance with a scan speed during the scan exposure process.

The substrate may comprise a wafer on which a pattern is formed.

Said method may further comprise detecting characteristic data related to plural wafers each having the same pattern as of said wafer, memorizing measurement position information determined on the basis of the characteristic data, and performing surface position measurement to each of said plural wafers on the basis of at least one of the memorized measurement positions.

In accordance with a further aspect of the present invention, there is provided a surface position setting method for setting a surface position of a substrate, said method comprising: a measuring step for measuring a surface position of the substrate surface at a measurement position, while relatively scanning the substrate surface relative to the measurement position; a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at a predetermined position in a scan direction, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value; a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related to those measurement positions before and after the particular location.

In said determining step, the target value in relation to the particular location may be determined on the basis

of interpolation of the measured values related to those measurement positions before and after the particular location.

The interpolation may comprise one of linear interpolation and multiple approximation interpolation.

Said method may further comprise measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

In accordance with a still further aspect of the present invention, there is provided a scanning exposure method for printing a pattern of an original on to a substrate while relatively scanning the original and the substrate, said method comprising: a measuring step for measuring a surface position of the surface of the substrate at a measurement position, while relatively scanning the substrate surface relative to the measurement position; a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at an exposure position, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value; a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related to those measurement positions before and after the particular location.

In said determining step, the target value in relation to the particular location may be determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.

The interpolation may comprise one of linear interpolation and multiple approximation interpolation.

Said method may further comprise measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

Embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a main portion of a slit scan type projection exposure apparatus which uses a surface position detecting method according to an embodiment of the present invention.

Figure 2 is a schematic view for explaining positional relationship between an exposure slit and measurement points, in the surface position detection through a

detection optical system of the Figure 1 embodiment.

Figure 3 is a schematic plan view for explaining an example of disposition of exposure regions on a wafer and selection of sample shots for prescan in an embodiment of the present invention.

Figure 4 is a flow chart for explaining outline of sequence from wafer loading to wafer unloading, in the apparatus of Figure 1.

Figures 5A and 5B are schematic views, respectively, for explaining measurement points on a chip of a wafer and measured values at these measurement points, in the embodiment of Figure 1.

Figure 6 is a schematic view for explaining the phenomenon which may occur at a surface level difference between chips of a wafer, in the embodiment of Figure 1.

Figures 7A and 7B are schematic views, respectively, for explaining detection signals produced in the embodiment of Figure 1.

Figure 8 is a flow chart for explaining outline of the sequence for measurement point selection, offset measurement and surface position correction drive for each shot in the exposure process, in a surface position detecting method according to an embodiment of the present invention.

Figure 9 is a schematic view for explaining an error related to sensor mounting position, in an example according to the present invention.

Figure 10 is a schematic view for explaining the relationship between wafer height, exposure region and height measurement position.

Figure 11 is a schematic view for explaining the relation between wafer height, exposure region and height measurement position, in a second embodiment of the present invention.

Figures 12A and 12B are schematic views, respectively, for explaining the relation between the wafer height and positional deviation of X stage, in the second embodiment of the present invention.

Figure 13 is a flow diagram of a method of manufacturing semiconductor devices;

Figure 14 is a flow diagram of wafer processing.

[First Embodiment]

Figure 1 is a schematic view of a portion of a slit-scan type projection exposure apparatus which is based on a surface position detecting method according to an embodiment of the present invention.

Denoted in Figure 1 at 1 is a reduction projection lens having an optical axis, denoted at AX in the drawing, and an image plane which is placed perpendicularly to Z direction illustrated. Reticle 2 is held by a reticle stage 3. The pattern of the reticle 2 is projected in a reduced scale of 1/4 or 1/2, according to the magnification of the projection lens, whereby an image of the pattern is formed on the image plane of the projection lens. Denoted at 4 is a wafer having a resist coating on its surface. There are a number of exposure zones (shots) on

the wafer surface, which have been defined through a preceding exposure process or processes. Denoted at 5 is a stage for carrying a wafer thereon. The stage 5 includes a chuck for holding the wafer 4 on the wafer stage, by attraction, an X-Y stage being horizontally movable in X-axis and Y-axis directions, a leveling stage being movable in Z-axis direction (optical axis direction of the projection lens 1) and also being rotationally movable about axes parallel to the X and Y axes, respectively, and a rotatable stage being rotationally movable about an axis parallel to the Z axis. The stage mechanism thus provides a six-axis correction system for bringing a reticle pattern image into registration with each exposure zone on the wafer.

The elements in Figure 1 denoted by reference numerals 1 - 10 function as components of a detection optical system for detecting the surface position or tilt of the wafer 4. Denoted at 10 is a light source. It may comprise a white lamp, or it may comprise an illumination unit which is arranged to project light of a high-luminance light emitting diode, having different peak wavelengths. Denoted at 11 is a collimator lens which receives the light from the light source 10 and projects parallel light having substantially uniform sectional intensity distribution. Denoted at 12 is a slit member of prism-like shape, and it comprises a pair of prisms being cemented to each other so that their slant surfaces are opposed to each other. At the cemented surfaces, there are plural openings (e.g., six pinholes) which are defined by use of s chromium film, for example. Denoted at 13 is a lens system of dual-telecentric system, which serves to direct six light beams having passed through the pinholes of the slit member 12, respectively, to six measurement points on the wafer 4 surface, via a mirror 14. While only two beams are illustrated in the drawing, each beam represents there beams juxtaposed in parallel to each other with respect to the direction perpendicular to the sheet of the drawing. Here, with respect to the lens system 13, the plane on which the pinholes are formed and the plane including the wafer 4 surface are set to satisfy the Scheimpflug's condition.

In this embodiment, the incidence angle θ of each light beam from the light projecting means on to the wafer 4 surface (the angle with respect to a normal to the wafer surface, i.e., with respect to the optical axis) is $\theta = 70$ deg. or more. As shown in Figure 3, there are a plurality of pattern regions (exposure zone shots) juxtaposed, on the wafer 4 surface. The six light beams passing the lens system 13 are incident on separate measurement points in a particular pattern region, as shown in Figure 2, and they are imaged thereon. Also, in order that the six measurement points may be observed upon the wafer 4 surface independently of each other, the light beams are projected in a direction rotated by an angle θ (e.g., 22.5 deg.) within the X-Y plane, from the X direction (scan direction).

The above-described arrangement enables optimum spatial disposition of various components, as pro-

posed in Japanese Patent Application, Application No. 157822/1991, filed in the name of the assignee of the subject application, and ensures high-precision detection of surface position information.

Next, the portion for detecting reflection light from the wafer 4, namely, components 15 - 19, will be described. Denoted at 16 is a light receiving lens of dual telecentric system, which serves to receive six reflection light beams from the wafer 4 surface. Stopper 17 disposed within the light receiving lens 16 serves as a common stop in relation to the six measurement points, and it serves to block higher-order diffraction light (noise light) which may be created by a circuit pattern formed on the wafer 4. The light beams passing the light receiving lens 16, comprising a dual telecentric lens system, have their optical axes disposed parallel to each other, and they are re-imaged upon a detection surface of a photoelectric converting means group 19, by means of six separate correction lenses of a correction optical system group 18, so that they form light spots of the same size upon the detection surface. This light receiving side, namely, components 16 - 18, is arranged to provide tilt correction so that all the measurement points on the wafer 4 surface and the detection surface of the photoelectric converting means group 19 are placed in an optically conjugate relation with each other. Therefore, any local inclination at any measurement point does not cause change in position of a pinhole image upon the detection surface. Thus, in response to a change in level (height) of each measurement point with respect to the optical axis AX direction, the pinhole image displaces upon the detection surface.

Here, the photoelectric converting means group 19 comprises six one-dimensional (linear) CCD line sensors. This is advantageous over use of a two-dimensional (area) sensor, in the following points. First, because of separation of photoelectric converting devices, in design of the correction optical system group 18, the latitude of disposition of various optical elements and a mechanical holder becomes larger. Further, while the optical magnification from the mirror 15 to the correction optical system group 18 should be made large for enhanced resolution of detection, also in this respect, the arrangement of dividing the light path so that separate lights are incident on individual sensors, respectively, enables compact disposition of elements. Moreover, in the slit-scan method, it is inevitable to execute successive focus measurements during the exposure process and therefore reduction of measurement time is an absolutely required factor. With conventional two-dimensional CCD sensor, although it may be attributable to reading-out of data, more than required, it takes a read-out time ten times longer or more of that with a one-dimensional CCD sensor.

Next, an exposure system of slit-scan type will be described.

As shown in Figure 1, the reticle 2 is held by attraction on the reticle stage 3. Thereafter, it is scanningly

moved at a constant speed, along a plane perpendicular to the optical axis AX of the projection lens 1 and in a direction RX (X-axis direction). Also, with respect to a direction RY (Y-axis direction, perpendicular to the sheet of the drawing), correction drive of the reticle is performed so that a target coordinate position is constantly scanned. Positional information of the reticle stage with respect to the X direction and the Y direction, is continuously measured by projecting a plurality of laser beams, from an external reticle interferometer system (X and Y) 21, on to an X-Y bar mirror 20 which is fixedly provided on the reticle stage 3 of Figure 1.

Exposure illumination optical system 6 uses a light source, such as an excimer laser, for example, which produces pulse light. While not shown in the drawing, the exposure illumination optical system 6 further comprises a beam shaping optical system, an optical integrator, a collimator and a mirror, for example. These components are made of a material or materials effectively transmit or reflect pulse light of deep ultraviolet region. The beam shaping optical system serves to transform a received light beam into a desired sectional shape, including size. The optical integrator serves to uniform the distribution characteristic of light so that the reticle 2 may be illuminated with uniform illuminance. By means of a masking blade, not shown, provided in the exposure illumination optical system 6, a rectangular illumination region corresponding to the chip size is defined. A pattern of the reticle 2 as locally or partially illuminated with that illumination region, is projected by the projection lens 1 on to the wafer 4 which is coated with a resist material.

Main control 27 shown in Figure 1 controls the whole system so that the scanning exposure process is performed to scaningly expose a predetermined zone on the wafer 4 with a slit image of the reticle 2, while adjusting the position within the X-Y plane (X and Y positions as well as rotation θ about an axis parallel to Z axis) and the position in Z direction (rotations α and β about axes parallel to X and Y axes, respectively, as well as height Z along the Z axis). More specifically, as regards alignment of the reticle pattern within the X-Y plane, control data is calculated from positional data obtained through the reticle interferometer 21 and a wafer stage interferometer 24 as well as from wafer positional data obtained through an alignment microscope, not shown. In accordance with the thus produced control data, a reticle position control system 22 and a wafer position control system 25 are controlled, to accomplish the alignment. When the reticle stage 3 is scaningly moved in a direction of an arrow 3a in Figure 1, the wafer stage 5 is moved in a direction of an arrow 5a in Figure 1, at a speed corrected in accordance with the reduction magnification of the projection lens. The scanning speed of the reticle stage 3 may be determined to provide a higher throughput, on the basis of the width of the masking blade (not shown) of the exposure illumination optical system 6 in the scan direction and the sensitivity

of a resist material applied to the wafer 4 surface.

As regards alignment of the reticle pattern with respect to the Z-axis direction, namely, registration with the image plane, it is performed so that, on the basis of the result of calculation in a surface position detecting system 26 which serves to detect height data of the wafer 4, the leveling stage of the wafer stage is controlled by means of the wafer position control system 25. More specifically, from the height data at three measurement light spots, for wafer surface level measurement, defined in the vicinity of the slit with respect to the scan direction, the tilt in a direction perpendicular to the scan direction as well as the height with respect to the optical axis AX direction are calculated. Then, on the basis of this, correction amount for optimum image plane position, at the exposure position, is determined. Correction is made in accordance with this determination.

Next, a method of detecting the position of an exposure region on the wafer 4, in accordance with a surface position detecting method of the present invention, will be explained. Referring first to the flow chart of Figure 4, an outline of the correction method will be described.

In response to a start command at step 101, a wafer is loaded on to the stage, and it is attracted to and held by the chuck, at step 2. Thereafter, for measurement of surface shape inside an exposure region of a chip, at step 103 prescan measurement is performed in a predetermined sample shot region. Then, at step 104, by using measured scan focus detection value, measurement points for measurement of focus detection value, best for correction of the exposure region into the exposure image plane position, are selected. After the selection, at step 105, for determination of a correction term for specifying the surface shape within the exposure region of the chip, prescan measurement is performed again with respect to plural sample shot regions. At step 106, by using measured scan focus detection value, a correction term for correcting the measured value, during the scan, into the optimum exposure image plane position, is determined. After calculation of correction term, at step 107 the scan exposure sequence for respective exposure positions is initiated, and, while correcting a focus detection value at a selected measurement position with the correction value, calculation of correction amount for registering the exposure region with the exposure image plane as well as corrective drive are performed.

Next, a method of measurement position selection for measurement of a best focus detection value, will be described in detail. Before it, a method of determining a focus measurement point in scanning exposure process, will be explained. Since in the stepper type exposure process the stage is stopped at the exposure position, determination may be accomplished by measuring the focus at the stopped position and correcting it, that is, by performing focus and tilt measurement with respect to at least one location common to shots. Since

however in the scan type exposure process the stage moves continuously during the exposure of shot, measurement has to be made to plural points in the shot. Further, the measurement position or timing has to be determined in consideration of many factors such as association with a driving system, slit width, scan speed and the like. If, as for such determination factors, there are a slit width W_s , a focus measurement time T_m , a focus correction time T_d and a stage scan speed V , in a case where the periodicity of surface irregularity of the exposure region is f , from the sampling theorem the correction cycle $1/(T_m+T_d)$ in the exposure process should be not smaller than $2f$. Namely, if the period of surface irregularity, taking a peripheral circuit portion as one period, is 3 mm, then the cycle time in a case where the correction including detection and/or correction of that surface irregularity is to be executed should be not longer than $3/(2 \times V)$. In such case, if the scan speed V is $V = 100$ mm/sec., the cycle time is equal to 15 ms. If correction is included and in consideration of response time of the driving system, it may be difficult to accomplish. A practical solution may be slowing down the scan speed. However, it is not desirable because the throughput reduces. If however this time period is assigned only to the detection, the detection can well be accomplished and it is possible to detect the surface state of the wafer. From this point, with the method in which the surface state is detected by prescan and the characteristic of surface irregularity of the exposure surface is detected thereby and in which the measurement position in actual exposure process, as necessary for detection in actual exposure process and as can be corrected from the correction cycle time, is determined, it is possible to provide a scan system which enables focus correction without decreasing the throughput. Also, since in exposure process the exposure area has a finite slit width W_s , for each slit size a correction precision similar to that of a stepper can be accomplished, provided that a relation with which focus measurement can be performed with respect to at least one point within the slit, namely, a relation $W_s/V > (T_m+T_d)$, is satisfied. In consideration of that focus is averaged during the scan exposure, it will be readily understood that such correction system as described is good enough.

[Example 1]

An example of scan measurement of focus value to an exposure region of a wafer, while holding the stage height correction system fixed, will now be described. As shown in Figure 5A, an exposure region is divided into four zones, and measurement is made to thirteen points while scanning these zones with five focus measurement sensors a - e. Figure 5B shows the result of measurement. In Figure 5B, for better understanding, measured values of sensors b and d are not plotted. The axis of abscissa denotes position coordinate in scan direction, and the axis of ordinates represents focus

measured value. Each dot represents a measured result at a measurement position by a corresponding sensor. Curves in the drawing are approximation curves as having been calculated in accordance with a least square method, for example. The surface irregularity of a wafer should inherently be less than the tolerance depth of a projection lens. However, at a portion of a scribe line or a peripheral circuit portion, there may be inclination of a resist surface such as shown in Figure 6. In such portion, reflection light can not be collected accurately, and a detection waveform may be such as shown in Figure 7B, having a peak P2 (asymmetric) or a peak P3 (weak peak). In such occasion, the result of processing will not reflect the actual value. If, as described, an approximation curve is determined by calculation from measured values, obtained through scan measurement, while holding the stage fixed, and deviation between an actually measured value and the approximation curve is detected at each measurement position, and if the amount of deviation exceeds a predetermined value, correct focus detection can be attained by excluding such measurement point out of the measurement points during actual scan exposure. Also, if in all the measured values the amount of deviation is large, such as in the case of the measured values of the sensor c in Figure 5B, all the measurements at that position may be disregarded as null, and correction amount of focus or tilt may be calculated on the basis of the remaining sensors. By selecting those positions where measurement results are stable, as described above, it is possible to obtain stable measured values over the whole wafer surface and, thus, to perform correct focus detection to the whole wafer surface.

Referring to Figure 8, correction sequence will be explained. At step 1, a wafer is loaded and it is attracted and held by a chuck. At step 2, measurement points for first prescan, that is, optional measurement points in shot for second prescan or those for exposure process, are calculated. More specifically, from the standpoint of response time of a correction system or the sampling theorem as described hereinbefore, a necessary and sufficient number of measurement points is calculated. In this case, taking a number larger than the number of measurement points in the exposure process may be advantageous in respect to determination of measurement points at step 7 below. Except a case where the subject to be examined is a first print, at this stage of procedure the alignment measurement to the whole wafer is effected and the positioning is completed. Then, at step 3, a shot about the center of the wafer, which is less affected by the chuck, is selected as the subject shot to measurement in the first prescan, and focus position correction is performed with respect to the shot center. After this, the stage will be moved only in the scan direction, and Z-direction correction will not be made.

At step 4, the stage is moved to the first measurement point as calculated at step 2. At step 5, a focus

measured value Z_{ij} ($j = 1$ to 5) at that position is measured, and it is memorized. Then, with loop checking at step 6, the procedure is looped until measurements at all the measurement points n are completed. At step 7, approximation curves such as shown in Figure 5B are determined by calculation, from all the measured values of Z_{ij} having been stored in a memory. Deviation between the actually measured value and the approximation curve is detected, with respect to each of the measured positions. If the deviation is larger than a predetermined value, corresponding measurement point may be excluded from the measurement points in actual scan exposure. Those measurement points P_{ij} , for which deviation has been determined as large, may be excluded from the measurement points in later measurement operations. Also, in consideration of response speed for correction, measurement points in exposure process are determined so that a necessary least number is selected and there does not occur eccentricity of measurement points. More specifically, those portions may be selected so that a scribe line is excluded, that the correction cycle is approximately periodic and that change in measurement value is slow. Although there may be a case where the surface has extraordinarily large surface irregularity or a case where measurement points can not be selected, in such occasion it is not always necessary that the measured values at the measurement points are effective for all the five points. If there is a sufficient span, at least two points may be enough to calculate the tilt amount. For those final measurement points thus determined, at step 8 the second prescan is performed to measure offset of the measurement system which may be attributable to resist surface irregularity, for example. With the procedure described above, selection of optimum measurement points and measurement offset at those positions, for correctly bringing each exposure region into registration with the focal plane of the projection system, are determined. On the basis of the data thus obtained, the wafer exposure procedure at steps 9 to 16 is performed. After completion of exposures of all the exposure shots of the wafer, checked at step S16, the wafer is unloaded at step 17.

[Example 2]

In this example, like Example 1 described above, scan measurement of focus value is performed to the exposure region of a wafer, while holding the state height correction system fixed. Simultaneously with calculation of measured values, a characteristic parameter of a detected waveform is calculated. As has been described hereinbefore, in a height detection system of oblique light projection type, the detection light path is limited so as to detect only the reflection light having substantially the same angle as the incidence angle, in order to avoid noise light. For this reason, there is a possibility that, if a surface having a small inclination is to

be detected, the intensity of detected light become extraordinarily low. For example, a focus detection waveform in a case of first print may have good balance and good symmetry such as shown in Figure 7A, because there is no pattern formed on the wafer. If the process goes on, however, there may be produced an asymmetry (P2) or degraded S/N (P3) where the intensity of detected light is extraordinarily low. This may cause a measurement error or distributed results. In such occasion, however, by calculating the characteristic amount of the waveform itself, that is, the quantity of reflected light or symmetry of the waveform, for example, it is possible to discriminate whether the point is appropriate for obtaining a stable measured value or not, without relying on statistically processing the measurement results. At step 5 of Figure 8, in the focus measurement, calculation of characteristic amount such as described above is executed additionally, and the result is memorized. At step 8 later, discrimination is made to it. By these processes, it is possible to enhance the reliability of measurement point selection.

[Example 3]

For measurement through the first prescan, from the relation described hereinbefore, a larger measurement points may be attainable with shorter measurement time and, as a consequence of it, more accurate characteristic of surface irregularity in the exposure region can be detected. However, this applies a larger load to the measurement system. While the scan speed during the exposure process may be changed in accordance with the resist sensitivity or the required throughput, it is not necessary that the measurement by the first prescan is effected at the same speed as the scan speed in the exposure process, since the measurement by first prescan is to be done only to a single shot of a first wafer of one lot. Rather, executing measurements to many points at a slow speed will be convenient for selection of positions for focus measurement in the exposure process. More particularly, in determination of optional measurement points at step 2 of Figure 8, a particular note is paid to assure that extraordinary point calculation at step 7 can be performed without difficulty and, as an example, measurement points are determined so that detection marks are superposed one upon another sufficiently. Also, the scan speed during the first prescan measurement is determined while giving the priority to the response speed of the measurement system. When discrimination of extraordinary value is to be made on the basis of the measured values thus obtained, an extraordinary point can be easily selected and excluded by, for example, passing a measured value of a certain sensor through a high-frequency passing filter. Also, for enhanced precision of measured value in determination of measurement points, waveform data may be taken N times per one-point measurement and, after data taking at all the measurement points, the measured

values of respective points may be calculated. An average of measured values of very N-time measurements at one point may be used as a measured value at that point. Alternatively, measurement data may be taken at points of a number, larger than the number of measurement points during the actual exposure process, and through a slow-speed scan, and average calculation may be made with respect to a few points (this can be called "movement average") to thereby prepare the data for calculation of optional measurement points.

[Example 4]

In the point of matching between plural apparatuses, the relation between the focus beam position and the exposure position has to be controlled precisely. For example, in an occasion where, with respect to the scan direction, the above-described relation varies between separate apparatuses, even if calibration is made to the image plane position and the focus measurement origin by executing an actual exposure process, the result depends on the measurement position in the scan direction and, therefore, it is not possible to accomplish correct focus offset correction without determining it in every apparatus. Further, if an adjusting mechanism is added to assure matching between separate apparatuses in respect to the above-described relation, it causes an increase in size and cost.

In consideration of this, the above-described relation may be detected beforehand, and the relative difference of them may be controlled as an offset. In that occasion, it is possible, in the selection of measurement points, to assure matching between the apparatuses as corrected. Also, once the exposure condition is determined with respect to one apparatus, the values of that condition may be applied to the other apparatuses. This will be explained in greater detail, in conjunction with Figure 9, portions (a) - (b'). It is now assumed that the calibration between the focus original and the projection lens image plane is made in a first apparatus A, under the condition shown in Figure 9, portion (a), that is, under the relation Da between the exposure slit position and the exposure position as illustrated. If a correction value obtained thereby is to be applied to a second apparatus B which is under the condition shown in Figure 9, portion (b), the result is that the position to be observed with a focus detection beam in the state in which the lens vs. stage positioning has been in the relation Da above, differs from that in the first apparatus A. Consequently, what is detected in this case is the position which is deviated by the difference in distance between the exposure slit position and the focus detection beam position, namely, by the difference between the apparatuses in the mount position of the focus detection system. Due to such difference in mounting position between separate apparatuses, calibration has to be done with respect to each of the apparatuses. However, by executing the procedure at step 2 and step 7 of Figure

7 while taking into account the difference in mount position of focus detection system, between separate apparatuses, as shown in Figure 9, portion (b'), the necessity of calibration for every apparatus can be avoided, and simple operation and control is assured.

The prescan measurement for selection of measurement positions as described hereinbefore may be performed at respective processes where patterns to be formed are different. However, it is sufficient to execute the measurement only to one wafer of one lot. For the same process to be performed later, the measurement positions as determined with respect to the first wafer in the lot and stored in a memory may be used in the focus measurement and correction, with good results. High precision leveling correction and exposure can be attained without decreasing the throughput. If it is expected that the wafers in one lot have large differences, prescan measurement for measurement position selection may be performed with respect to a few wafers, and common measurement positions to those wafers may be used with respect to the remaining wafers. This may assure further enhancement of precision.

[Second Embodiment]

A second embodiment of the present invention will now be described. Since a slit-scan type exposure system to be used in this embodiment has an essentially the same structure as of the first embodiment described above, explanation of it will be omitted here. In the following, a method of detecting the height position (level) of an exposure region of a wafer 4 in accordance with a surface position detection of the present invention will be described.

Figure 10(a), shows the relation between a wafer height measurement position and the position of exposure region during the wafer exposure process. It is assumed here that a pattern of a reticle is going to be printed on an exposure region C on the surface of a wafer 41 which is being moved in a direction of an arrow X. In Figure 10(a), height measuring means 40B is provided at a position before the center A of the exposure region C with respect to the wafer movement direction, which position is spaced by a distance d from the center A. At the moment as the point A comes to a position just below the height measuring means 40B, the height of the wafer surface at the point A is measured. Then, at the moment as the point A comes to the center of the exposure region C, the wafer height is adjusted into registration with the exposure plane. The wafer height measurement sampling interval in this case corresponds to the time period by which the wafer moves through the distance d.

When the height of the wafer surface should be changed during the exposure process, there may be three cases. First is for variation with a change in height within a chip. Second is for variation at the junction (scribe line) of chips. Third is for variation as an exposure region comes from the outside into the inside of the

wafer. As regards the variation within a chip, since the cell portion and the peripheral circuit portion may be generally flattened through a CMP process, for example, the surface level difference may be about 1 - 2 microns. As regards the surface level difference between the chip and the scribe line, while it may be larger than that within the chip, any way it may be within a range of a few microns. To these variations, for exposure of an outer peripheral portion of a wafer, the wafer surface is first held at an appropriate level. Then, after the height measuring means comes to a position on the wafer where the height measurement is attainable, the height measurement is performed. Then, until the exposure region moves on to the wafer, the height drive is performed. As a consequence, there are cases in which the wafer height should be changed by about ten microns within a time period in which the wafer moves through the distance from the center of the exposure region to the wafer height measuring sensor.

Thus, the response speed of the wafer height control system should not be determined in consideration of the surface level difference within the wafer only. Rather, the response speed of the wafer height control system should be determined in the case as the measuring system comes from the outside into the inside of the wafer during the exposure process. For this reason, the response speed of the wafer height control system has a sufficient speed, enough for drive through a distance corresponding to the variation in height within the chip. In the time period in which the wafer moves through a distance from the center of the exposure region to the wafer height measuring sensor.

Figure 10(c) shows the relation among a wafer surface 41, a wafer height 44 as moved, and a focus error 45 in a case where, in the example of Figure 10(a), the response speeds of the detection system and the driving system are higher as compared with the wafer scan speed. Since the response speed is higher than the measurement interval, there is a larger focus error between measurement points.

Figure 10(d) shows an example where the sampling interval is 1/5 of that of the Figure 10(c) example. Also, there is shown the relation among a wafer surface 41, a wafer height 46 as moved, and a focus error. It is seen that, as compared with Figure 10(c), the focus error is smaller. However, since one-dimensional CCD line sensors are used in the photoelectric converting means group 19, and from the relation between the light quantity of the light source 10 and the accumulation time of CCD, it is not possible to reduce the sampling time immoderately. Further, even if the light quantity of the light source 10 is enlarged and the sampling interval is made shorter, the quantity of traffic flowing through the data bus of the measurement system may also increase, such that the control system may become complicated and expensive. Any way, since the exposure region has a fixed width in the wafer scan direction, it is substantially impossible to follow the surface irregularity of a pe-

riod shorter than that width. Thus, performing the measurement with an excessively short interval is not meaningful.

In the present embodiment, in consideration of the above, the sampling interval d is unchanged and, in place, the interval of drive signal application is made shorter than the sampling interval. Also, this interval of drive signal application is made shorter than the response time of the control system. As regards the data between sampling points, those which are obtainable through interpolation, such as linear interpolation or multiple approximation interpolation, of values based on measured data obtained at plural sampling points, including the preceding sampling point and the subsequent sampling point, are used.

Figure 11 illustrates an example of drive during wafer exposure process, according to the present invention. For simplicity of illustration, it is assumed that there is only one wafer height measuring means, the movement and measurement direction is in the same direction (Z direction) as the direction of the lens optical axis, and there is no drive in the wafer tilt direction (α or β). The wafer height measurement sampling interval is still d , and Z-position drive signals are applied with an interval $d/5$. The response time of the Z stage control system is longer than the time period in which the wafer moves through a distance $d/5$. At the measurement step N-1, the wafer height measuring means measures the position of the point N on the wafer. The center of the exposure region is at the position of point N-1, wherein the position N-1 is outside the wafer. Further, designated drive amount between these steps is the one as obtained through interpolation of height measured values obtained by the preceding and succeeding measurements.

Under these conditions, at step N-1, the wafer surface is not at the exposure position, and an appropriate drive designation signal is applied to move the Z stage at an appropriate position. This position may be at a predetermined height from the wafer chuck, or it may be the height of the wafer position closest to the wafer position having been measured earlier. Alternatively, a value at an outside peripheral portion of the wafer may be measured beforehand, and the measured value may be used. The designated drive amount between step N-1 and step N may be obtained through interpolation, on the basis of the wafer surface height as detected at step N-1 and of the drive designated value at the step N-1.

At step N, the center of exposure position comes on to the wafer, and the wafer exposure process is initiated. The height drive correction value at step N is the value which is based on the wafer height measured value at step N-1 and, at this moment, the wafer surface height at step N+1 is performed. The drive designated value from step N to step N+1 may be determined through interpolation, on the basis of the wafer surface height at the center of exposure position in step N+1, as measured at step N (i.e., measurement position of the wafer

height measuring means at step N) as well as the wafer height drive designated value for step N. Similar operations as described above are repeated with respect to step N+2 and steps following it, and wafer height drive is performed during the exposure process.

With the procedure of this embodiment described above, the focus error is reduced. Also, since the target value is changed with intervals shorter than the response speed of the Z stage control system, there does not occur vibration which otherwise may be produced in the drive during convergence to a target value. Further, the measurement time is longer as compared with a case where the sampling interval is made equal to $d/5$, the system can be structured by use of a simple control system.

As regards the target value to be applied, the response of the control system may be taken into account such that a value corresponding to response delay may be added to the value obtained through interpolation.

While in Figure 11 the wafer height measurement and the Z-position drive signal application in each step are performed at the same timing, the timing of Z-position drive signal application may be changed while taking the delay of driving system into account. Further, while in the illustrated example there is no drive in the wafer tilt direction (α or β), as a matter of course, the present invention is applicable also to measurement and drive with respect to such tilt direction.

On the other hand, application of the present invention is effective to solve a problem of degradation of line width precision due to abbe correction. Figure 12A shows motion of an X-stage in relation to abbe correction, wherein the axis of abscissa denotes time. The spacing between points a and k corresponds to the time required for a wafer to scan through the distance d between the center of exposure region and the wafer height detection system. The response speed of the stage is the time required for the wafer to move through a distance $d/2$. Points a, b, ..., and k represent the timing of sampling and rewriting of target value, for wafer and reticle stage interferometers. Z sampling and driving is performed only once during the period from a to k.

In Figure 12A, denoted at 50 is a read-out value of the interferometer in a case where there is no Z-axis drive. Inherently, it should be illustrated by a curve since the target value varies between points a and k. For convenience in explanation, however, it is illustrated with a constant target value between points a and k. If Z-axis drive is effected at timing of point f, the read-out value of the interferometer may shift as depicted at 51, by an amount corresponding to an abbe error. In order to correct this, the target value is corrected at timing of point h by an amount corresponding to the abbe error. Since however the amount of correction at 52 is large, deviation of the X stage from its target value becomes large, after point g, as depicted at 53.

Figure 12B shows motion of the X-stage in relation to the abbe correction, in a case where the present in-

vention is applied. Z-axis drive is effected at timings of points a, c, e, g, i, and k. The target value for the interferometer is changed at points c, d, f, h, and j, in accordance with the drive amounts of a, c, e, g, i, and k, respectively. Final correction values for the interferometer, namely, those at 52 and 55, are of the same amount. However, since the target value for the stage (i.e., the correction value for the interferometer) is changed with intervals faster than the response speed of the X-stage and the correction is done frequently, stage vibration is not created and the deviation 56 from the target value is smaller than that at 53.

As described, when the present invention is applied to a case where an abbe error produced by Z-position drive is to be corrected, it is possible to reduce the positional error in X direction, such that an exposure process of free from or with reduced variation in printed line width is enabled. Although the foregoing description has been made with respect to the X-stage which moves in the scan direction, the same applies to a Y stage. The abbe correction may be made with respect to the reticle stage side, not on the wafer stage side. However, in such occasion, the correction amount may increase in accordance with the magnification of the reduction projection lens.

(Third Embodiment)

An explanation will be given below about the third embodiment of a method for manufacturing semiconductor devices by using the SOR exposure system described above.

Fig. 13 is a flowchart showing the sequence of the operation of manufacturing semiconductor devices (semiconductor chips, such as ICs or LSIs, liquid-crystal panels, or CCDs).

Referring to the flowchart shown in Fig. 13 in step 1 (circuit design), circuits of semiconductor devices are designed. In step 2 (manufacture of masks), masks having designed circuit patterns formed thereon are manufactured. In step 3 (manufacture of wafers), wafers are manufactured by using materials, such as silicon. Step 4 (wafer process) is called a pre-step, whereby actual circuits are formed on wafers by lithography technology by using the masks and wafers produced as described above. The subsequent step 5 (fabrication) is called a post step, whereby semiconductors are formed into chips by using the wafers manufactured in step 4. This step includes an assembly step (dicing, bonding), a packaging step (enclosing chips), and the like. In step 6 (inspection), inspection, for example, a test for confirming the operations of semiconductor devices manufactured in step 5, or a durability test, is performed. Semiconductor devices are completed through the processes described above and shipped (step 7).

Fig. 14 shows a detailed flowchart for the wafer process. In step 11 (oxidation), the surface of the wafer is oxidized. In step 12 (CVD), an insulating film is formed

on the surface of the wafer. In step 13 (electrode - formation), electrodes are formed on the wafer by deposition. In step 14 (ion implantation), ions are implanted into the wafer. In step 15 (resist process), a photosensitizing agent is applied to the wafer. In step 16 (exposure), a circuit pattern of the mask is printed and exposed to the wafer by means of the SOR exposure system of the above-described embodiment. In step 17 (development), the exposed wafer is developed. In step 18 (etching), portions other than the developed resist image are etched. In step 19 (resist peel-off), resists which become unnecessary after etching is performed are removed. Circuit patterns are formed on the wafer in a multi-form by performing these steps repeatedly.

While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is intended to cover such modifications or changes as may come within the purposes of the improvements or the scope of the following claims.

Claims

1. A surface position detecting method for detecting a surface position of a surface to be examined, having surface height irregularity, while relatively scanning the surface, said method comprising the steps of:

detecting characteristic data related to a surface state at plural measurement positions on the surface, while relatively scanning the surface; and

processing the detected characteristic data related to the measurement positions to determine a measurement position for measurement of the surface position in a subsequent surface position detecting process.

2. A method according to Claim 1, wherein, in said characteristic data detection, surface position data and a characteristic amount which represents a shape of a detection signal are detected.

3. A scanning exposure method for printing a pattern of an original on to a substrate while relatively scanning the original and the substrate, said method comprising the steps of:

detecting characteristic data related to a surface state at plural measurement positions on the surface of the substrate, while relatively scanning the substrate surface; and
processing the detected characteristic data related to the measurement positions to determine a measurement position for measurement of the surface position to the substrate surface in surface position detection during a scanning

exposure process.

4. A method according to Claim 3, wherein, in said characteristic data detection, surface position data and a characteristic amount which represents a shape of a detection signal are detected.

5. A method according to Claim 3, wherein said characteristic data detection includes detecting the characteristic data while performing the relative scan at a scan speed lower than the scan speed during the scan exposure process.

6. A method according to Claim 3, wherein said determination of measurement position includes determination of a measurement position for measurement of the surface position of the substrate surface in accordance with a scan speed during the scan exposure process.

7. A method according to Claim 3, wherein the substrate comprises a wafer on which a pattern is formed.

8. A method according to Claim 7, further comprising detecting characteristic data related to plural wafers each having the same pattern as of said wafer, memorizing measurement position information determined on the basis of the characteristic data, and performing surface position measurement to each of said plural wafers on the basis of at least one of the memorized measurement positions.

9. A surface position setting method for setting a surface position of a substrate, said method comprising:

a measuring step for measuring a surface position of the substrate surface at a measurement position, while relatively scanning the substrate surface relative to the measurement position;

a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at a predetermined position in a scan direction, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value;

a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and

a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related

to those measurement positions before and after the particular location.

10. A method according to Claim 9, wherein, in said determining step, the target value in relation to the particular location is determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.

11. A method according to Claim 10, wherein the interpolation comprises one of linear interpolation and multiple approximation interpolation.

12. A method according to Claim 9, further comprising measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

13. A scanning exposure method for printing a pattern of an original on to a substrate while relatively scanning the original and the substrate, said method comprising:

a measuring step for measuring a surface position of the surface of the substrate at a measurement position, while relatively scanning the substrate surface relative to the measurement position;

a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at an exposure position, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value;

a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and

a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related to those measurement positions before and after the particular location.

14. A method according to Claim 13, wherein, in said determining step, the target value in relation to the particular location is determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.

15. A method according to Claim 14, wherein the interpolation comprises one of linear interpolation and multiple approximation interpolation.

16. A method according to Claim 13, further comprising measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

17. A device manufacturing method comprising the scanning exposure method according to any one of claims 3 to 8 or 13 to 16, and the step of fabricating a device using the exposed substrate.

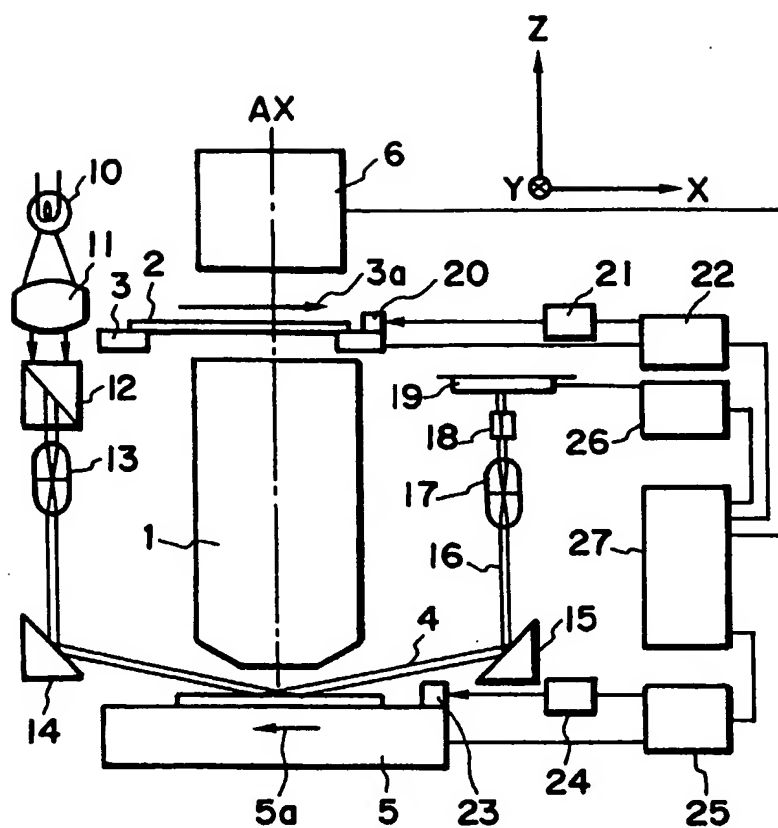


FIG. 1

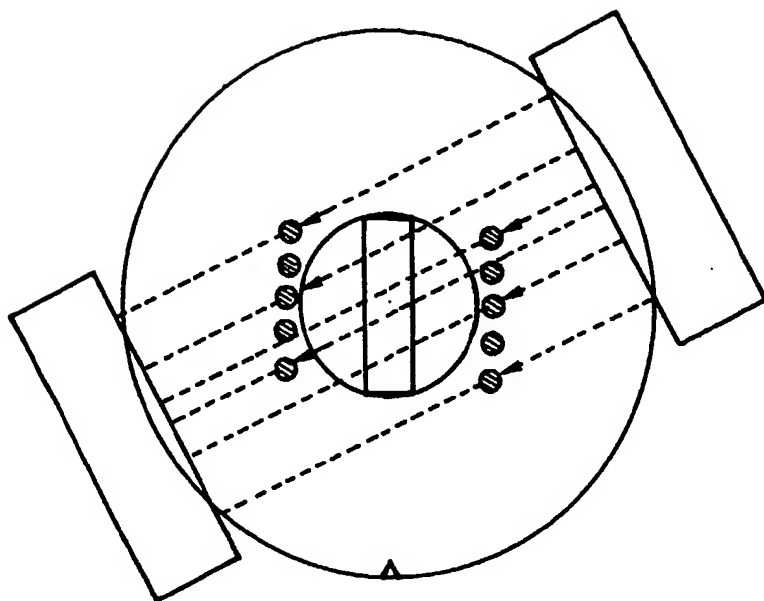


FIG. 2

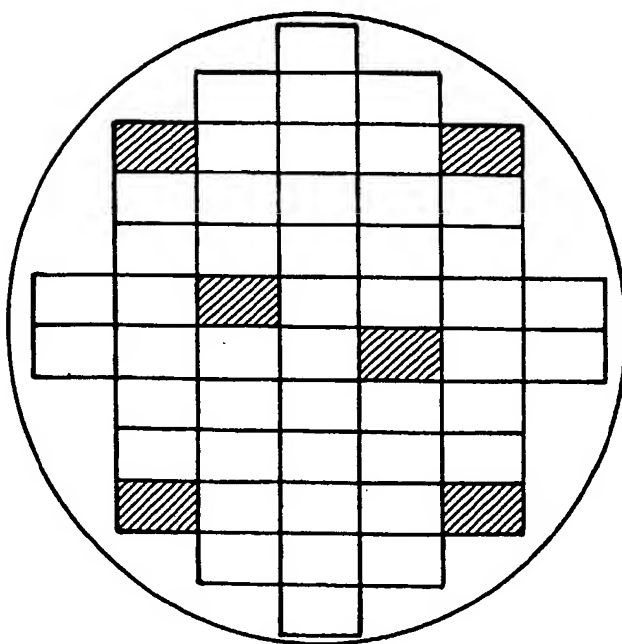


FIG. 3

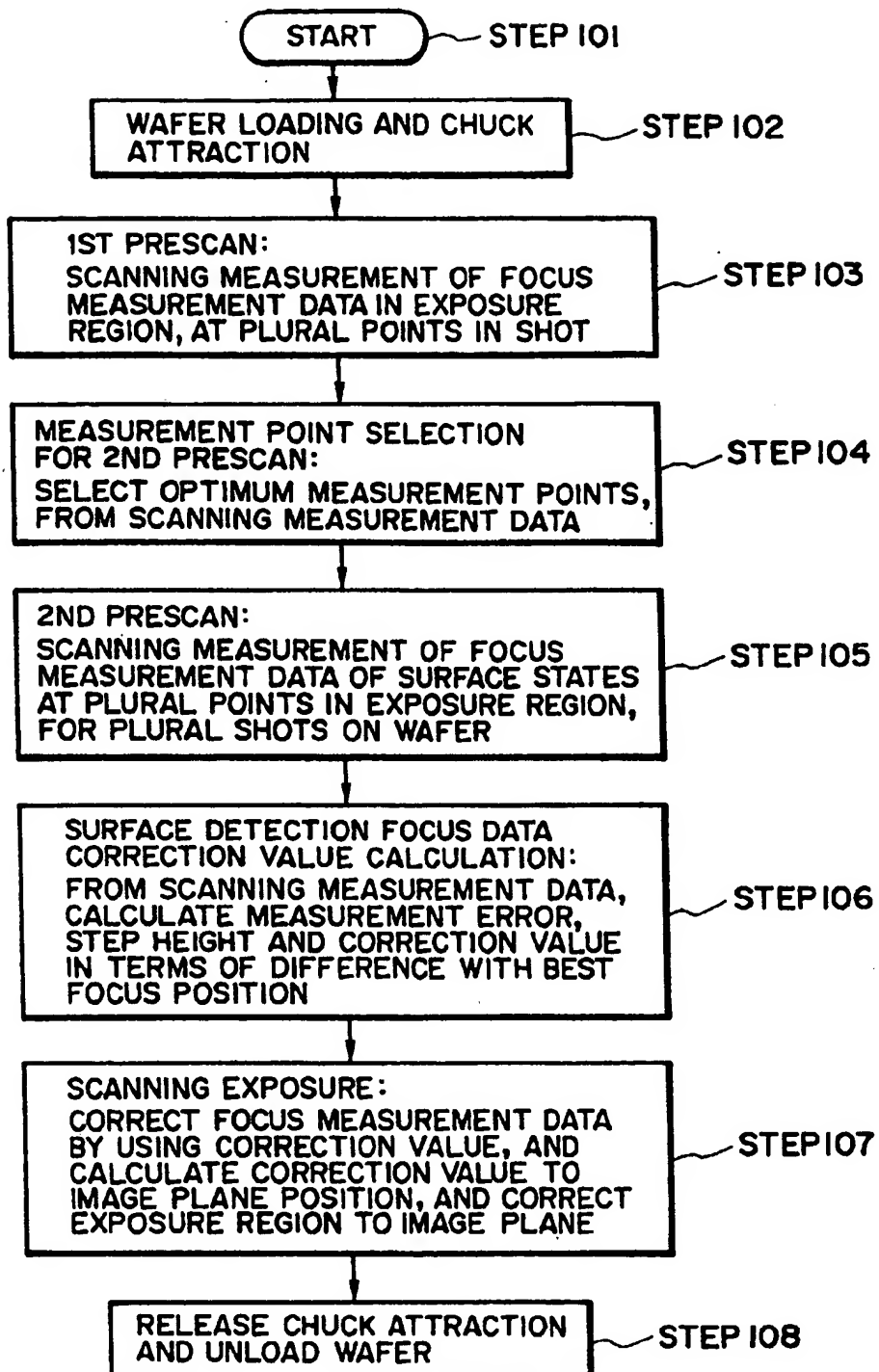


FIG. 4

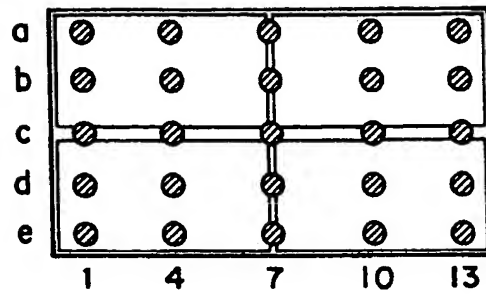


FIG. 5A

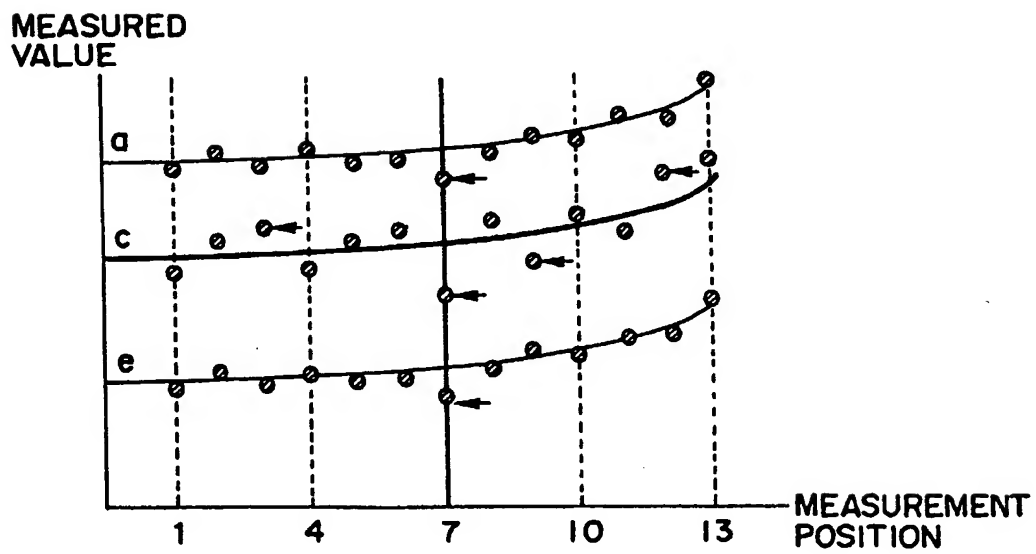


FIG. 5B

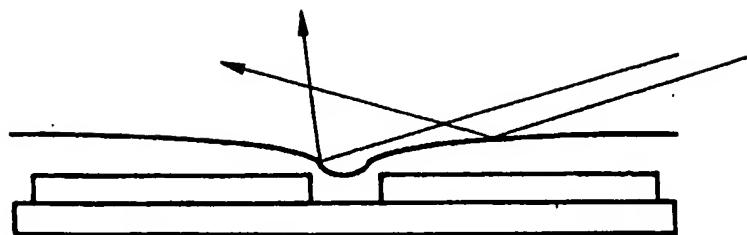


FIG. 6

FIG. 7A

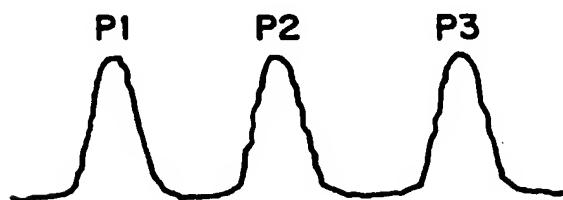
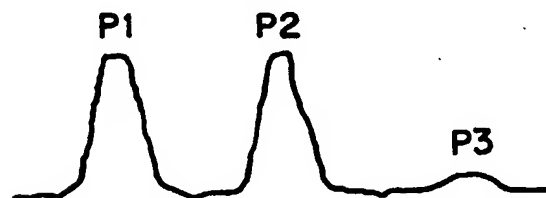


FIG. 7B



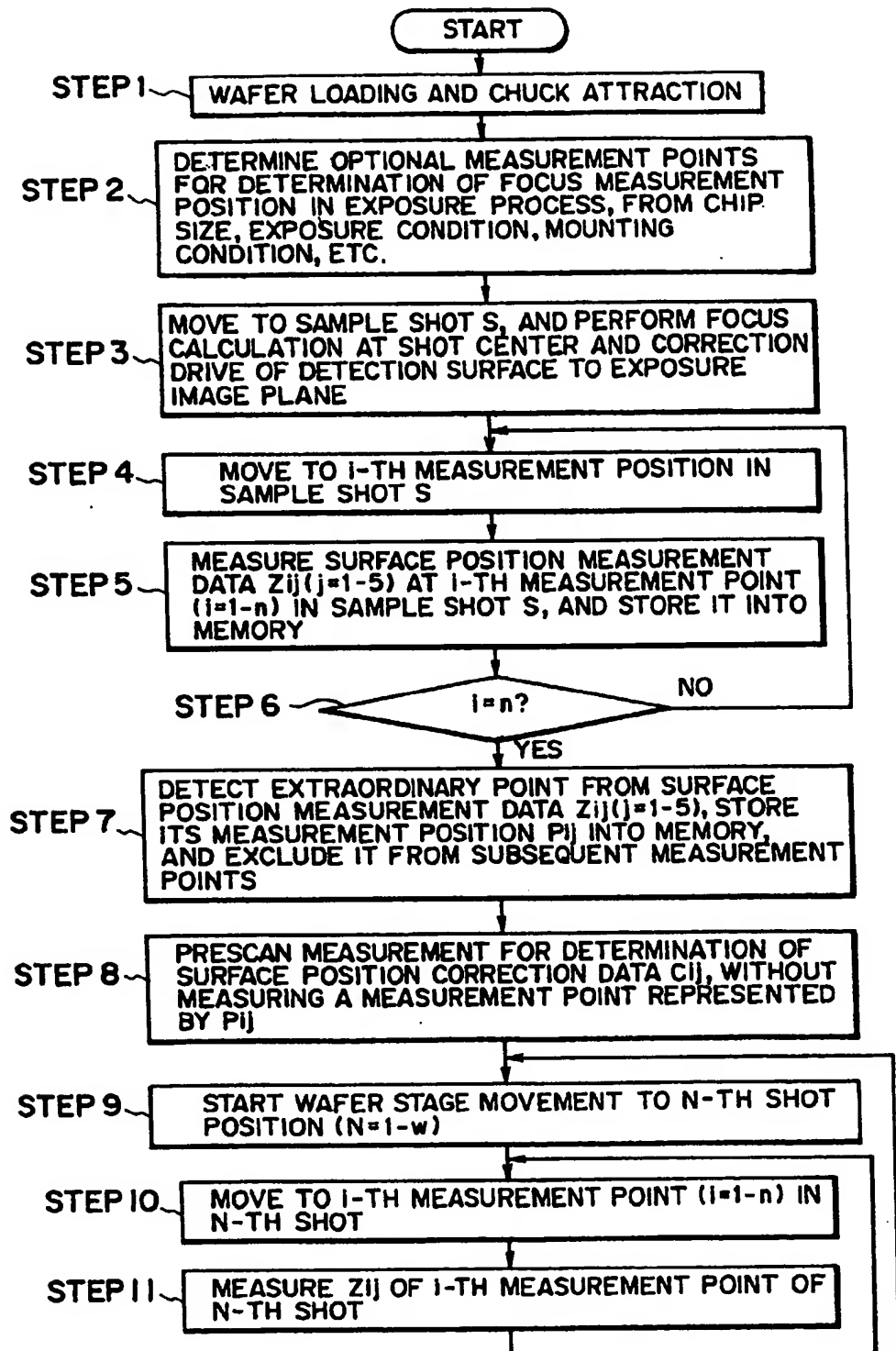


FIG. 8A

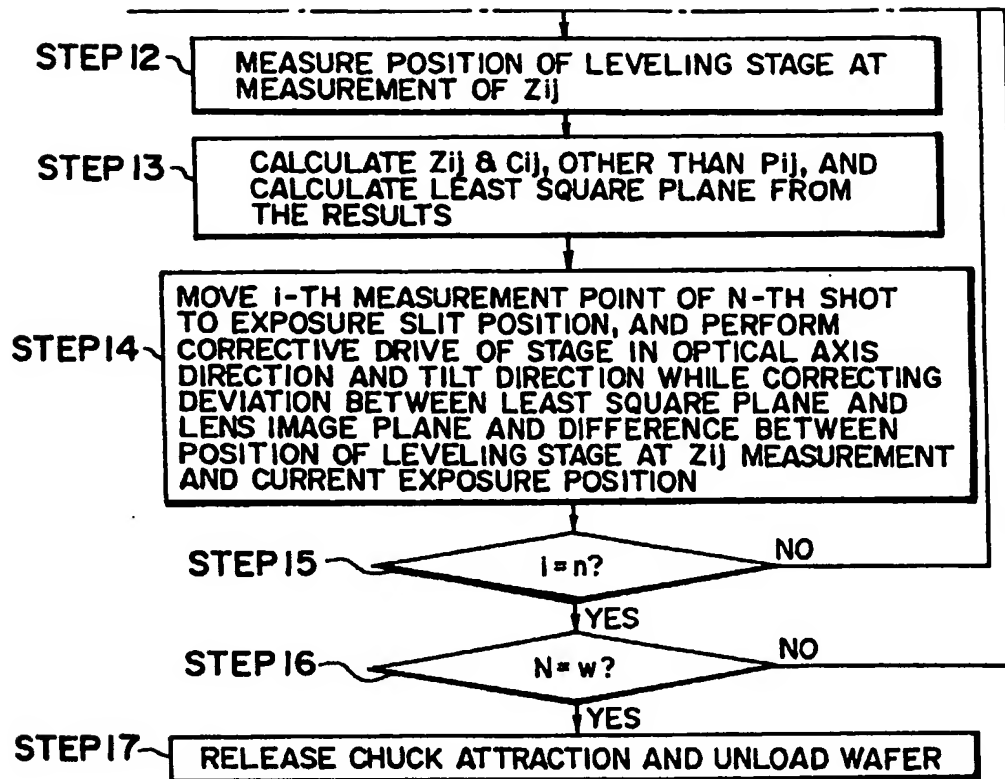


FIG. 8B

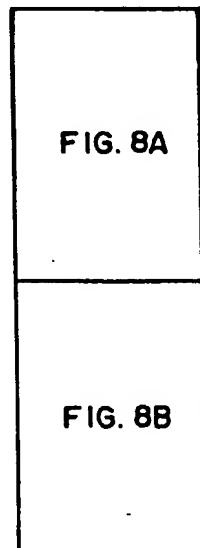


FIG. 8

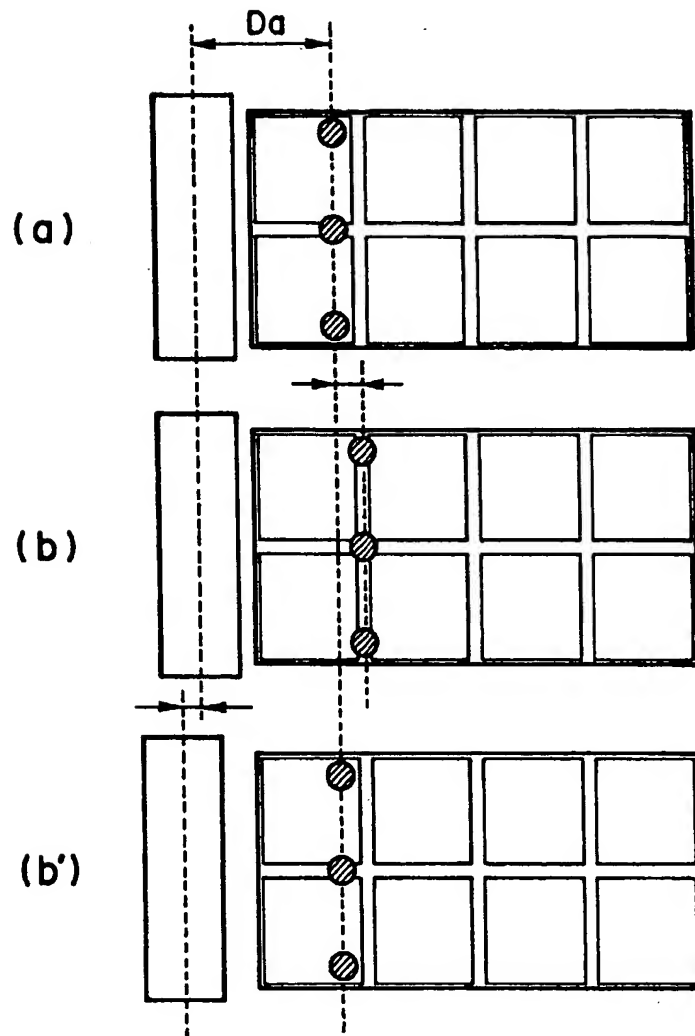


FIG. 9

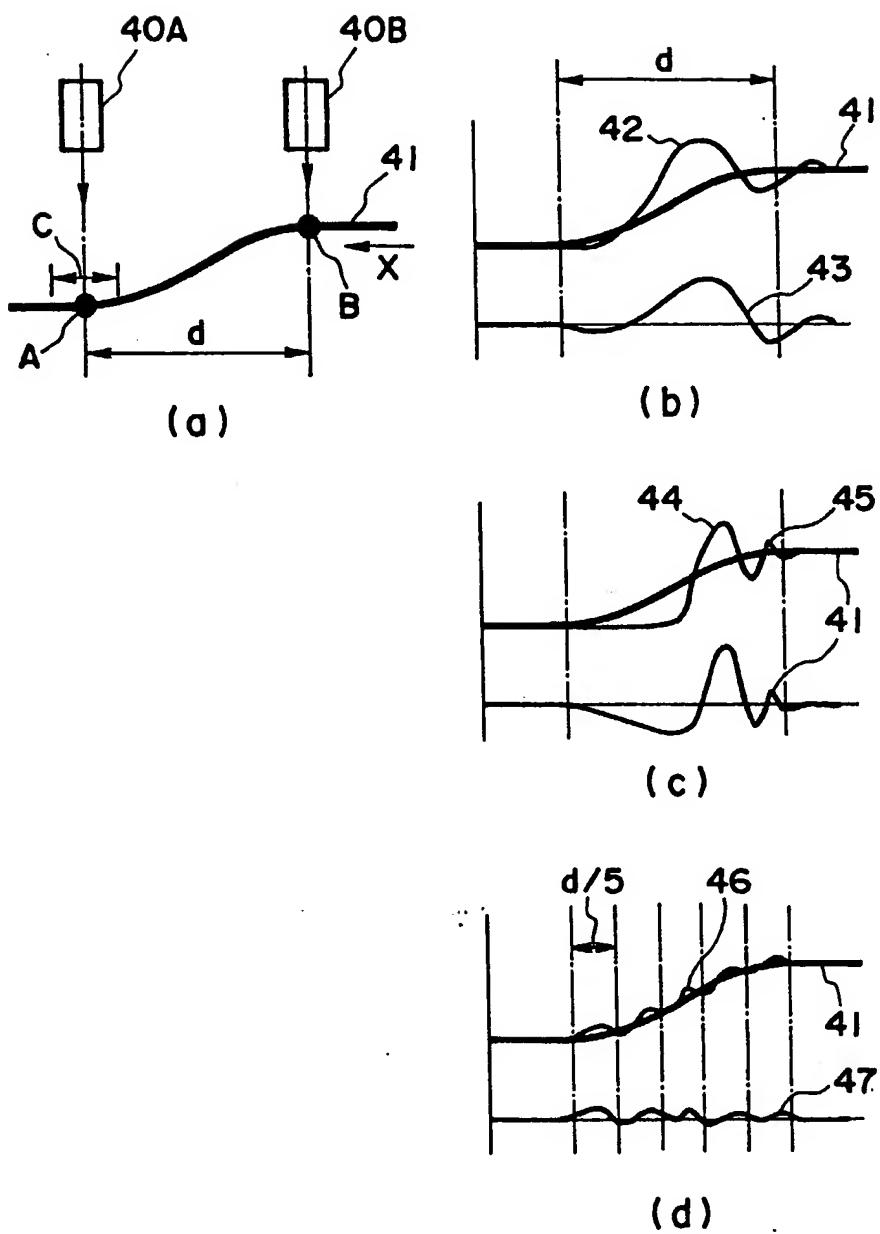


FIG. 10

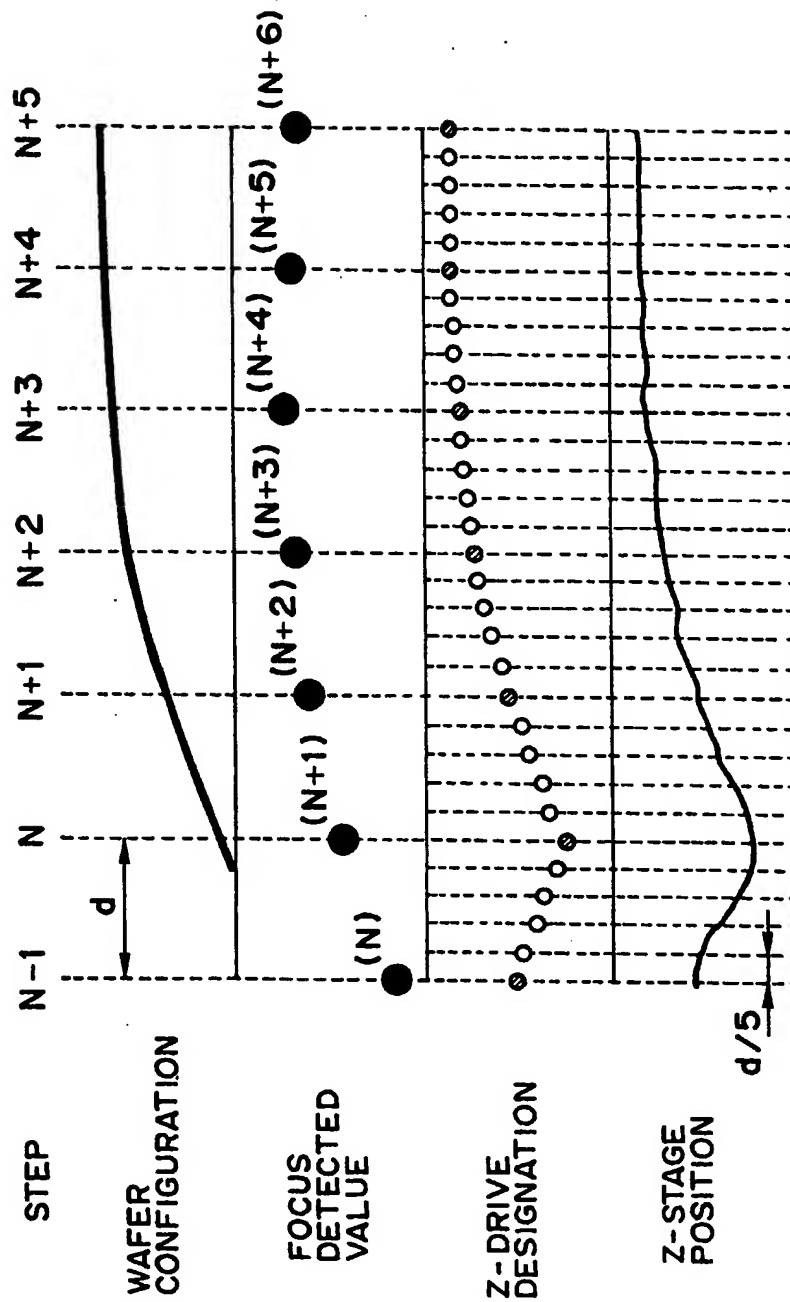


FIG. 11

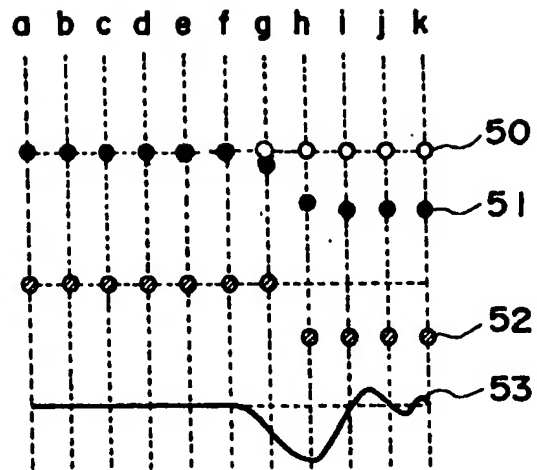


FIG. 12A

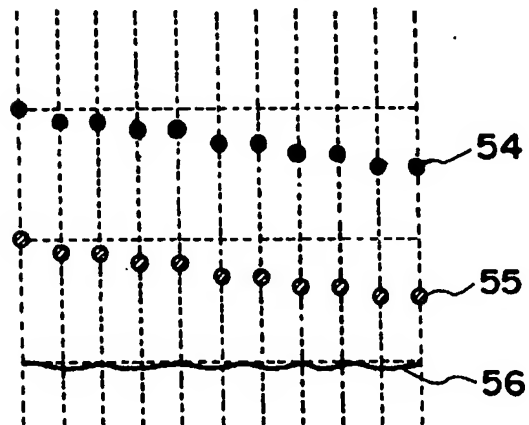
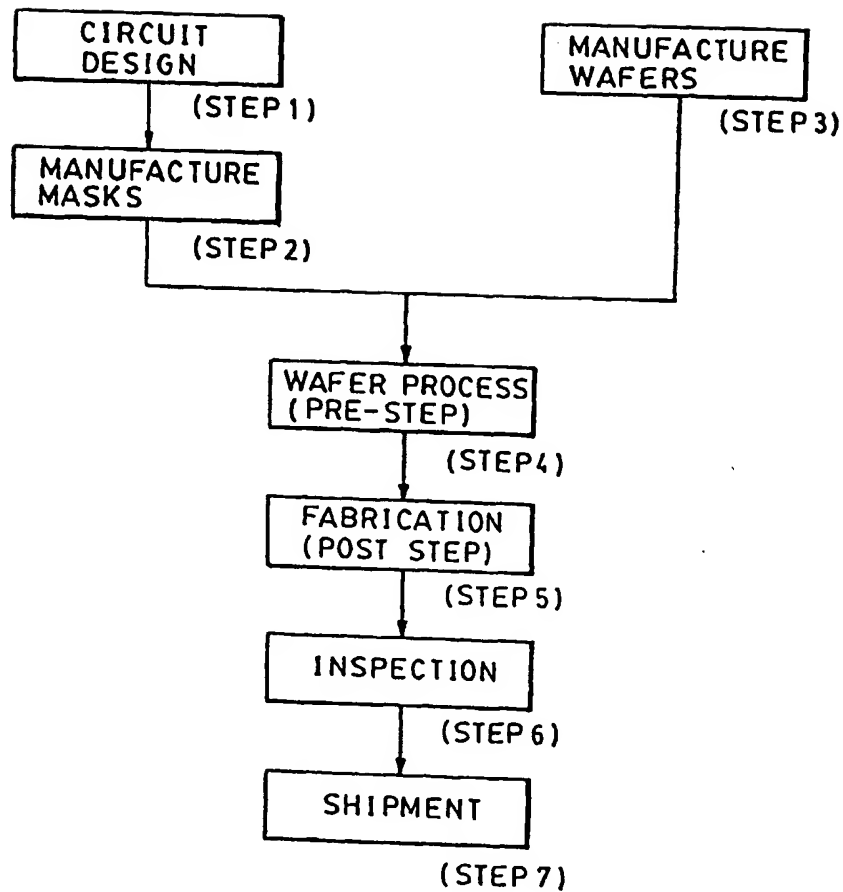


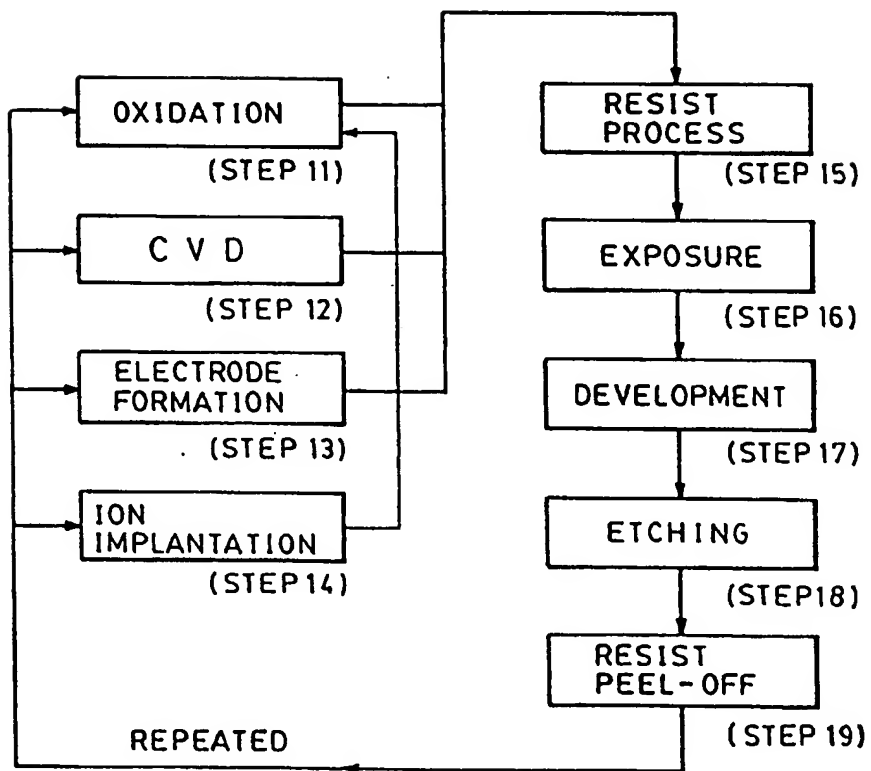
FIG. 12B

FIG. 13



FLOW FOR MANUFACTURING
SEMICONDUCTOR DEVICES

FIG. 14



WAFER PROCESS



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(71) Applicant: **CANON KABUSHIKI KAISHA
Tokyo (JP)**

(72) Inventors:
• **Iwanaga, Takehiko
Ohta-ku, Tokyo (JP)**

• **Yamada, Yuichi
Ohta-ku, Tokyo (JP)**
• **Uzawa, Shigeyuki
Ohta-ku, Tokyo (JP)**

(74) Representative:
**Beresford, Keith Denis Lewis et al
BERESFORD & Co.
2-5 Warwick Court
High Holborn
London WC1R 5DJ (GB)**

(54) **Surface position detecting method and scanning exposure method using the same**

(57) A surface position detecting method for detecting a surface position of a surface to be examined, having surface height irregularity, while relatively scanning the surface, is disclosed. The method includes detecting characteristic data related to a surface state at plural

measurement positions on the surface, while relatively scanning the surface, and processing the detected characteristic data related to the measurement positions to determine a measurement position for measurement of the surface position in a subsequent surface position detecting process.

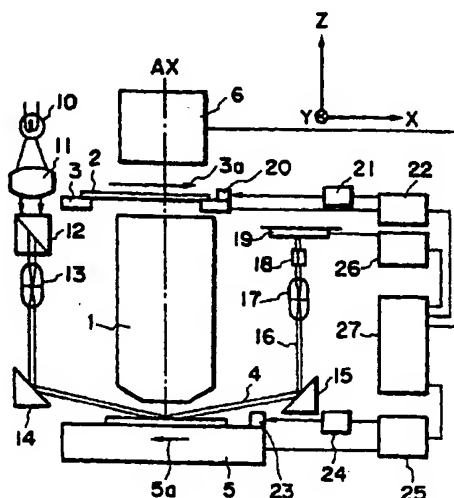


FIG. 1

EP 0 793 073 A3



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EUROPEAN SEARCH REPORT

Application Number
EP 97 30 1291

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (In I.C.I.6)
Y	US 5 194 893 A (NISHI KENJI) 16 March 1993 * abstract; figure 1 * ---	1-4,7,17	G01B11/00 G01B11/06 G03F9/00 G03F7/20
Y	US 5 118 957 A (SUZUKI AKIYOSHI ET AL) 2 June 1992 * column 4 - column 5; figure 1 * ---	1-4,7,17	
A	EP 0 585 041 A (CANON KK) 2 March 1994 * abstract; figure 1 * ---	1,3	
A	EP 0 634 700 A (NIKON CORPORATION) 18 January 1995 * abstract; claim 1; figure 3 * ---	9,13	
A	US 5 477 304 A (NISHI KENJI) 19 December 1995 * abstract; figures 1,4 * -----	9,13	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			G01B G03F
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 28 July 1998	Examiner Vorropoulos, G
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

EPO FORM 1503 03 82 (P04C01)



European Patent
Office

Application Number

EP 97 30 1291

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing more than ten claims.

- ☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims and for those claims for which claims fees have been paid, namely claim(s):
- ☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for the first ten claims.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

- ☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.
- ☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:
- ☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:



European Patent
Office

LACK OF UNITY OF INVENTION
SHEET B

Application Number

EP 97 30 1291

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. Claims: 1-8 ,17

Optical surface position detecting method and its application in scanning exposure systems for manufacturing purposes.

2. Claims: 9-16

Surface position setting method and its application in scanning exposure systems

(19)



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(21) Application number: **97301291.7**

(22) Date of filing: **27.02.1997**

(54) **Surface position detecting method and scanning exposure method using the same**

Verfahren zur Detektion einer Oberflächenlage und Abtastbelichtungsverfahren unter Verwendung desselben

Procédé de détection de la position d'une surface et procédé d'exposition par balayage utilisant celui-ci

(84) Designated Contracting States:
DE GB NL

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01.03.1996 JP 6899996**

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01204135.6 / 1 195 647

(73) Proprietor: **CANON KABUSHIKI KAISHA
Tokyo (JP)**

(72) Inventors:
• **Iwanaga, Takehiko
Ohta-ku, Tokyo (JP)**

• **Yamada, Yulchi
Ohta-ku, Tokyo (JP)**
• **Uzawa, Shigeyuki
Ohta-ku, Tokyo (JP)**

(74) Representative:
**Beresford, Keith Denis Lewis et al
BERESFORD & Co.
2-5 Warwick Court,
High Holborn
London WC1R 5DH (GB)**

(56) References cited:
**EP-A- 0 585 041 EP-A- 0 634 700
US-A- 5 118 957 US-A- 5 194 893
US-A- 5 477 304**

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EP 0 793 073 B1

Description

[0001] This invention relates to a surface position setting method for setting a position of a substrate such as a wafer, for example. More particularly, the invention is concerned with a surface position setting method usable in a slit-scan type exposure apparatus. In a second aspect, the invention is concerned with a scanning exposure method for printing a pattern of an original onto a substrate using such surface position setting method.

[0002] The size of memory chips is recently increasing due to the difference between the tendency of cell size or resolvable line width of an exposure apparatus and the tendency of enlargement of memory capacity. As an example, for the first generation of 256M memories, the chip size is about 14 x 25 (mm).

[0003] For such chip size, with an exposure region of 31 mm diameter of a reduction projection exposure apparatus (stepper) currently used as an exposure apparatus for a critical layer, only one chip can be exposed with one exposure operation. Thus, the throughput is very low. An exposure apparatus capable of exposure with a larger area is therefore desirable.

[0004] As for large field size exposure apparatus, there are reflection projection exposure apparatuses which are widely used as a semiconductor device exposure apparatus for use for rough layer with which a high throughput is required, or as an exposure apparatus for manufacture of large-field liquid crystal display devices such as monitors. Exposure apparatuses of this category, like the one disclosed in US 5 477 304, comprise a slit scan type exposure apparatus which is based on mask-to-wafer relative scan wherein a mask is linearly scanned with illumination light of arcuate slit-like shape, and wherein a pattern of the mask is printed in a single exposure on to a wafer by means of a concentric reflection mirror optical system.

[0005] As regards the focusing of a mask image in these exposure apparatuses, in order to continuously keep the exposure surface of a photosensitive substrate (such as a wafer or a glass plate which is coated with a photoresist, for example) in registration with a best imaging plane of a projection optical system, height (level) measurement and autofocusing or auto-leveling correction drive are successively performed during the scan exposure process.

[0006] As for surface position detecting mechanism in such apparatuses, there is a method in which an oblique light projection optical system is used to project a light beam on to a wafer surface obliquely from the above and in which reflection light from the photosensitive substrate is detected as a positional deviation upon a sensor, and a method in which a gap sensor such as an air microsensor or an electrostatic capacity sensor is used. In these methods, from plural values of measured heights obtained during the scan, correction drive amount for height and tilt as a measurement position passes an exposure slit region is calculated and, based

on this, correction is made.

[0007] On the other hand, in the autofocusing or auto-leveling in a slit scan type exposure apparatus, a wafer moves during the exposure process and, for this reason, there is a possibility that, in accordance with the rate determination by the response speed of a focus plane detection system and of a wafer stage height (wafer height) driving system, a following-up error (i.e., focus error) is created.

[0008] This will be explained in detail, in conjunction with Figure 2. In Figure 2(a), it is assumed that a pattern of a reticle is going to be printed on an exposure region C on the surface of a wafer 41 which is being moved in a direction of an arrow X. If height measuring means 40A is provided at a position of the center A of the exposure region C and the wafer stage drive is made on the basis of a measured value therefrom, because of the response delay described above, the wafer surface can not follow the focus plane. In consideration of this, usually in scan type exposure apparatuses the height measuring means is provided at a position different from the point A on the exposure region C and the height of the wafer surface is measured beforehand. As that position comes to the exposure position, the wafer height is adjusted into the exposure plane. In Figure 2(a), height measuring means 40B is provided at a position before the exposure region center A with respect to the wafer movement direction, which position is spaced by a distance d from the center A. At the moment as the point A comes to the position just below the height measuring means 40B, the height of the wafer surface at the point A is measured. Then, at the moment as the point A comes to the position below the exposure region C, the wafer height is adjusted to the exposure plane. The sampling interval in this case corresponds to the time period ($t_s = d/s$ where s is the wafer scan speed) by which the wafer moves through the distance d.

[0009] Figure 2(b) shows the relation among a wafer surface 41, a wafer height 42 as moved, and a difference between the wafer surface 41 and the wafer height 42 as moved, that is, the focus error 43, in a case where the response speeds of the detection system and the driving system are slow as compared with the wafer scan speed (sampling interval t_s). Due to such response delay, there is a large focus error.

[0010] Figure 2(c) shows the relation among a wafer surface 41, a wafer height 44 as moved, and a focus error 45 in a case where the response speeds of the detection system and the driving system are higher as compared with the wafer scan speed. Since the response speed is higher than the measurement interval, there is a larger focus error between measurement points.

[0011] Figure 2(d) shows an example where the sampling interval is shortened so as to avoid this. The sampling interval is made to be equal to the time in which the wafer moves through a distance d/5. Also, there is shown the relation among a wafer surface 41, a wafer

height 46 as moved, and a focus error 47. The focus error is small, and good following-up is assured.

[0012] However, shortening the sampling interval will cause the following problems. As a result of flattening through a CMP method, for example, to the cell portion and the peripheral circuit portion, within the wafer surface there may be a surface level difference of only about 1 micron. However, when a wafer outer peripheral portion is to be exposed and the drive is to be made from the outside to the inside of the wafer, the wafer height has to be changed by a few tens microns within a time period in which the wafer moves through a distance d of the spacing of sensors. Thus, it is not possible to determine the sensor spacing d on the basis of only the surface level difference within the wafer. Further, when the sampling interval is to be reduced and if an accumulation type detecting means such as CCD, for example, is used, a finite accumulation time is necessary and it defines the rate determination. Also, the quantity of traffic flowing through the data bus of the measurement system increases. As a result, the control system becomes complicated and expensive.

[0013] The above-described points are problems of the wafer height measuring system. In addition to them, there is a problem of abbe error which may be created by inclination of the surface of a bar mirror of a laser interferometer when the wafer height is changed. In conventional apparatuses in which a wafer is exposed while it is held stationary, such abbe error is corrected by moving the stage in X and Y directions by an amount effective to correct other components (X and Y components) created by the wafer height driving. Moving the X-Y stage takes a longer time until the target position is reached as compared with a case where drive is made in the wafer height direction, since the mass of the components to be driven is larger. However, in this type of apparatuses, the exposure process starts after the X-Y stage reaches the target position. Thus, there is no possibility that the abbe correction has an influence upon the printing linewidth precision or exposure position precision, for example.

[0014] In scan type exposure apparatuses, however, since the abbe correction has to be done during scan of the stage, the following problem will arise. When a reticle and a wafer are scanned for exposure by use of a scan type exposure apparatus, the wafer stage and the reticle stage have a large mass as described and, therefore, fine control of them is not easy to achieve. Usually, drive pattern for them is based on a trapezoidal profile drive in which a constant-speed portion of the drive profile is used for the printing process. If abbe correction drive is added to this, the target value for the constant-speed profile portion during the printing process has to be rewritten. If the amount of changing the target value is large, vibration may be created in relation to the stage drive which vibration in turn may result in degradation of linewidth precision of the printing process. Such problem will be more notable with enlargement of the wafer

size to 25.4 cm (10 inch) or 30.48 cm (12 inch) wafer and with corresponding increases in mass of the stage.

[0015] In accordance with a first aspect of the present invention, there is provided a surface position setting method for setting a surface position of a substrate, said method comprising: a measuring step for measuring a surface position of the substrate surface at a measurement position, while relatively scanning the substrate surface relative to the measurement position; a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at a predetermined position in a scan direction, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value; a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related to those measurement positions before and after the particular location.

[0016] In said determining step, the target value in relation to the particular location may be determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.

[0017] The interpolation may comprise one of linear interpolation and multiple approximation interpolation.

[0018] Said method may further comprise measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

[0019] In accordance with a second aspect of the present invention, there is provided a scanning exposure method for printing a pattern of an original on to a substrate while relatively scanning the original and the substrate, said method comprising: a measuring step for measuring a surface position of the surface of the substrate at a measurement position, while relatively scanning the substrate surface relative to the measurement position; a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at an exposure position, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value; a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on

the basis of measured values related to those measurement positions before and after the particular location.

[0020] In said determining step, the target value in relation to the particular location may be determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.

[0021] The interpolation may comprise one of linear interpolation and multiple approximation interpolation.

[0022] Said method may further comprise measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

[0023] Embodiments of the present invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a main portion of a slit scan type projection exposure apparatus which uses a surface position detecting method according to an embodiment of the present invention.

Figure 2 is a schematic view for explaining the relationship between wafer height, exposure region and height measurement position.

Figure 3 is a schematic view for explaining the relation between wafer height, exposure region and height measurement position, in a second embodiment of the present invention.

Figures 4A and 4B are schematic views, respectively, for explaining the relation between the wafer height and positional deviation of X stage, in the second embodiment of the present invention.

Figure 5 is a flow diagram of a method of manufacturing semiconductor devices;

Figure 6 is a flow diagram of wafer processing.

[0024] Figure 1 is a schematic view of a portion of a slit-scan type projection exposure apparatus which is based on a surface position detecting method according to an embodiment of the present invention.

[0025] Denoted in Figure 1 at 1 is a reduction projection lens having an optical axis, denoted at AX in the drawing, and an image plane which is placed perpendicularly to Z direction illustrated. Reticle 2 is held by a reticle stage 3. The pattern of the reticle 2 is projected in a reduced scale of 1/4 or 1/2, according to the magnification of the projection lens, whereby an image of the pattern is formed on the image plane of the projection lens. Denoted at 4 is a wafer having a resist coating on its surface. There are a number of exposure zones (shots) on the wafer surface, which have been defined through a preceding exposure process or processes. Denoted at 5 is a stage for carrying a wafer thereon. The stage 5 includes a chuck for holding the wafer 4 on the wafer stage, by attraction, an X-Y stage being horizon-

tally movable in X-axis and Y-axis directions, a leveling stage being movable in Z-axis direction (optical axis direction of the projection lens 1) and also being rotationally movable about axes parallel to the X and Y axes, respectively, and a rotatable stage being rotationally movable about an axis parallel to the Z axis. The stage mechanism thus provides a six-axis correction system for bringing a reticle pattern image into registration with each exposure zone on the wafer.

[0026] The elements in Figure 1 denoted by reference numerals 1 - 10 function as components of a detection optical system for detecting the surface position or tilt of the wafer 4. Denoted at 10 is a light source. It may comprise a white lamp, or it may comprise an illumination unit which is arranged to project light of a high-luminance light emitting diode, having different peak wavelengths. Denoted at 11 is a collimator lens which receives the light from the light source 10 and projects parallel light having substantially uniform sectional intensity distribution. Denoted at 12 is a slit member of prism-like shape, and it comprises a pair of prisms being cemented to each other so that their slant surfaces are opposed to each other. At the cemented surfaces, there are plural openings (e.g., six pinholes) which are defined by use of s chromium film, for example. Denoted at 13 is a lens system of dual-telecentric system, which serves to direct six light beams having passed through the pinholes of the slit member 12, respectively, to six measurement points on the wafer 4 surface, via a mirror 14. While only two beams are illustrated in the drawing, each beam represents there beams juxtaposed in parallel to each other with respect to the direction perpendicular to the sheet of the drawing. Here, with respect to the lens system 13, the plane on which the pinholes are formed and the plane including the wafer 4 surface are set to satisfy the Scheinmpflug's condition.

[0027] In this embodiment, the incidence angle ϕ of each light beam from the light projecting means on to the wafer 4 surface (the angle with respect to a normal to the wafer surface, i.e., with respect to the optical axis) is $\phi = 70$ deg. or more. As shown in Figure 3, there are a plurality of pattern regions (exposure zone shots) juxtaposed, on the wafer 4 surface. The six light beams passing the lens system 13 are incident on separate measurement points in a particular pattern region, as shown in Figure 2, and they are imaged thereon. Also, in order that the six measurement points may be observed upon the wafer 4 surface independently of each other, the light beams are projected in a direction rotated by an angle θ (e.g., 22.5 deg.) within the X-Y plane, from the X direction (scan direction).

[0028] The above-described arrangement enables optimum spatial disposition of various components, as proposed in Japanese Patent Application, Application No. 157822/1991, filed in the name of the assignee of the subject application, and ensures high-precision detection of surface position information.

[0029] Next, the portion for detecting reflection light

from the wafer 4, namely, components 15 - 19, will be described. Denoted at 16 is a light receiving lens of dual telecentric system, which serves to receive six reflection light beams from the wafer 4 surface. Stopper 17 disposed within the light receiving lens 16 serves as a common stop in relation to the six measurement points, and it serves to block higher-order diffraction light (noise light) which may be created by a circuit pattern formed on the wafer 4. The light beams passing the light receiving lens 16, comprising a dual telecentric lens system, have their optical axes disposed parallel to each other, and they are re-imaged upon a detection surface of a photoelectric converging means group 19, by means of six separate correction lenses of a correction optical system group 18, so that they form light spots of the same size upon the detection surface. This light receiving side, namely, components 16 - 18, is arranged to provide tilt correction so that all the measurement points on the wafer 4 surface and the detection surface of the photoelectric converting means group 19 are placed in an optically conjugate relation with each other. Therefore, any local inclination at any measurement point does not cause change in position of a pinhole image upon the detection surface. Thus, in response to a change in level (height) of each measurement point with respect to the optical axis AX direction, the pinhole image displaces upon the detection surface.

[0030] Here, the photoelectric converting means group 19 comprises six one-dimensional (linear) CCD line sensors. This is advantageous over use of a two-dimensional (area) sensor, in the following points. First, because of separation of photoelectric converting devices, in design of the correction optical system group 18, the latitude of disposition of various optical elements and a mechanical holder becomes larger. Further, while the optical magnification from the mirror 15 to the correction optical system group 18 should be made large for enhanced resolution of detection, also in this respect, the arrangement of dividing the light path so that separate lights are incident on individual sensors, respectively, enables compact disposition of elements. Moreover, in the slit-scan method, it is inevitable to execute successive focus measurements during the exposure process and therefore reduction of measurement time is an absolutely required factor. With conventional two-dimensional CCD sensor, although it may be attributable to reading-out of data, more than required, it takes a read-out time ten times longer or more of that with a one-dimensional CCD sensor.

[0031] Next, an exposure system of slit-scan type will be described.

[0032] As shown in Figure 1, the reticle 2 is held by attraction on the reticle stage 3. Thereafter, it is scan-
ningly moved at a constant speed, along a plane perpendicular to the optical axis AX of the projection lens 1 and in a direction RX (X-axis direction). Also, with respect to a direction RY (Y-axis direction, perpendicular to the sheet of the drawing), correction drive of the reticle

is performed so that a target coordinate position is constantly scanned. Positional information of the reticle stage with respect to the X direction and the Y direction, is continuously measured by projecting a plurality of laser beams, from an external reticle interferometer system (X and Y) 21, on to an X-Y bar mirror 20 which is fixedly provided on the reticle stage 3 of Figure 1.

[0033] Exposure illumination optical system 6 uses a light source, such as an excimer laser, for example, which produces pulse light. While not shown in the drawing, the exposure illumination optical system 6 further comprises a beam shaping optical system, an optical integrator, a collimator and a mirror, for example. These components are made of a material or materials effectively transmit or reflect pulse light of deep ultraviolet region. The beam shaping optical system serves to transform a received light beam into a desired sectional shape, including size. The optical integrator serves to uniform the distribution characteristic of light so that the reticle 2 may be illuminated with uniform illuminance. By means of a masking blade, not shown, provided in the exposure illumination optical system 6, a rectangular illumination region corresponding to the chip size is defined. A pattern of the reticle 2 as locally or partially illuminated with that illumination region, is projected by the projection lens 1 on to the wafer 4 which is coated with a resist material.

[0034] Main control 27 shown in Figure 1 controls the whole system so that the scanning exposure process is performed to scaningly expose a predetermined zone on the wafer 4 with a slit image of the reticle 2, while adjusting the position within the X-Y plane (X and Y positions as well as rotation θ about an axis parallel to Z axis) and the position in Z direction (rotations α and β about axes parallel to X and Y axes, respectively, as well as height Z along the Z axis). More specifically, as regards alignment of the reticle pattern within the X-Y plane, control data is calculated from positional data obtained through the reticle interferometer 21 and a wafer stage interferometer 24 as well as from wafer positional data obtained through an alignment microscope, not shown. In accordance with the thus produced control data, a reticle position control system 22 and a wafer position control system 25 are controlled, to accomplish the alignment. When the reticle stage 3 is scaningly moved in a direction of an arrow 3a in Figure 1, the wafer stage 5 is moved in a direction of an arrow 5a in Figure 1, at a speed corrected in accordance with the reduction magnification of the projection lens. The scanning speed of the reticle stage 3 may be determined to provide a higher throughput, on the basis of the width of the masking blade (not shown) of the exposure illumination optical system 6 in the scan direction and the sensitivity of a resist material applied to the wafer 4 surface.

[0035] As regards alignment of the reticle pattern with respect to the Z-axis direction, namely, registration with the image plane, it is performed so that, on the basis of the result of calculation in a surface position detecting

system 26 which serves to detect height data of the wafer 4, the leveling stage of the wafer stage is controlled by means of the wafer position control system 25. More specifically, from the height data at three measurement light spots, for wafer surface level measurement, defined in the vicinity of the slit with respect to the scan direction, the tilt in a direction perpendicular to the scan direction as well as the height with respect to the optical axis AX direction are calculated.

Then, on the basis of this, correction amount for optimum image plane position, at the exposure position, is determined. Correction is made in accordance with this determination.

[0036] In the following, a method of detecting the height position (level) of an exposure region of a wafer 4 in accordance with a surface position detection of the present invention will be described.

[0037] Figure 2(a), shows the relation between a wafer height measurement position and the position of exposure region during the wafer exposure process. It is assumed here that a pattern of a reticle is going to be printed on an exposure region C on the surface of a wafer 41 which is being moved in a direction of an arrow X. In Figure 2(a), height measuring means 40B is provided at a position before the center A of the exposure region C with respect to the wafer movement direction, which position is spaced by a distance d from the center A. At the moment as the point A comes to a position just below the height measuring means 40B, the height of the wafer surface at the point A is measured. Then, at the moment as the point A comes to the center of the exposure region C, the wafer height is adjusted into registration with the exposure plane. The wafer height measurement sampling interval in this case corresponds to the time period by which the wafer moves through the distance d.

[0038] When the height of the wafer surface should be changed during the exposure process, there may be three cases. First is for variation with a change in height within a chip. Second is for variation at the junction (scribe line) of chips. Third is for variation as an exposure region comes from the outside into the inside of the wafer. As regards the variation within a chip, since the cell portion and the peripheral circuit portion may be generally flattened through a CMP process, for example, the surface level difference may be about 1 - 2 microns. As regards the surface level difference between the chip and the scribe line, while it may be larger than that within the chip, any way it may be within a range of a few microns. To these variations, for exposure of an outer peripheral portion of a wafer, the wafer surface is first held at an appropriate level. Then, after the height measuring means comes to a position on the wafer where the height measurement is attainable, the height measurement is performed. Then, until the exposure region moves on to the wafer, the height drive is performed. As a consequence, there are cases in which the wafer height should be changed by about ten microns

within a time period in which the wafer moves through the distance from the center of the exposure region to the wafer height measuring sensor.

[0039] Thus, the response speed of the wafer height control system should not be determined in consideration of the surface level difference within the wafer only. Rather, the response speed of the wafer height control system should be determined in the case as the measuring system comes from the outside into the inside of the wafer during the exposure process. For this reason, the response speed of the wafer height control system has a sufficient speed, enough for drive through a distance corresponding to the variation in height within the chip, in the time period in which the wafer moves through a distance from the center of the exposure region to the wafer height measuring sensor.

[0040] Figure 2(c) shows the relation among a wafer surface 41, a wafer height 44 as moved, and a focus error 45 in a case where, in the example of Figure 2(a), the response speeds of the detection system and the driving system are higher as compared with the wafer scan speed. Since the response speed is higher than the measurement interval, there is a larger focus error between measurement points.

[0041] Figure 2(d) shows an example where the sampling interval is 1/5 of that of the Figure 2(c) example. Also, there is shown the relation among a wafer surface 41, a wafer height 46 as moved, and a focus error. It is seen that, as compared with Figure 2(c), the focus error is smaller. However, since one-dimensional CCD line sensors are used in the photoelectric converting means group 19, and from the relation between the light quantity of the light source 10 and the accumulation time of CCD, it is not possible to reduce the sampling time immoderately. Further, even if the light quantity of the light source 10 is enlarged and the sampling interval is made shorter, the quantity of traffic flowing through the data bus of the measurement system may also increase, such that the control system may become complicated and expensive. Any way, since the exposure region has a fixed width in the wafer scan direction, it is substantially impossible to follow the surface irregularity of a period shorter than that width. Thus, performing the measurement with an excessively short interval is not meaningful.

[0042] In the present embodiment, in consideration of the above, the sampling interval d is unchanged and, in place, the interval of drive signal application is made shorter than the sampling interval. Also, this interval of drive signal application is made shorter than the response time of the control system. As regards the data between sampling points, those which are obtainable through interpolation, such as linear interpolation or multiple approximation interpolation, of values based on measured data obtained at plural sampling points, including the preceding sampling point and the subsequent sampling point, are used.

[0043] Figure 3 illustrates an example of drive during

wafer exposure process, according to the present invention. For simplicity of illustration, it is assumed that there is only one wafer height measuring means, the movement and measurement direction is in the same direction (Z direction) as the direction of the lens optical axis, and there is no drive in the wafer tilt direction (α or β). The wafer height measurement sampling interval is still d , and Z-position drive signals are applied with an interval $d/5$. The response time of the Z stage control system is longer than the time period in which the wafer moves through a distance $d/5$. At the measurement step N-1, the wafer height measuring means measures the position of the point N on the wafer. The center of the exposure region is at the position of point N-1, wherein the position N-1 is outside the wafer. Further, designated drive amount between these steps is the one as obtained through interpolation of height measured values obtained by the preceding and succeeding measurements.

[0044] Under these conditions, at step N-1, the wafer surface is not at the exposure position, and an appropriate drive designation signal is applied to move the Z stage at an appropriate position. This position may be at a predetermined height from the wafer chuck, or it may be the height of the wafer position closest to the wafer position having been measured earlier. Alternatively, a value at an outside peripheral portion of the wafer may be measured beforehand, and the measured value may be used. The designated drive amount between step N-1 and step N may be obtained through interpolation, on the basis of the wafer surface height as detected at step N-1 and of the drive designated value at the step N-1.

[0045] At step N, the center of exposure position comes on to the wafer, and the wafer exposure process is initiated. The height drive correction value at step N is the value which is based on the wafer height measured value at step N-1 and, at this moment, the wafer surface height at step N+1 is performed. The drive designated value from step N to step N+1 may be determined through interpolation, on the basis of the wafer surface height at the center of exposure position in step N+1, as measured at step N (i.e., measurement position of the wafer height measuring means at step N) as well as the wafer height drive designated value for step N. Similar operations as described above are repeated with respect to step N+2 and steps following it, and wafer height drive is performed during the exposure process.

[0046] With the procedure of this embodiment described above, the focus error is reduced. Also, since the target value is changed with intervals shorter than the response speed of the Z stage control system, there does not occur vibration which otherwise may be produced in the drive during convergence to a target value. Further, the measurement time is longer as compared with a case where the sampling interval is made equal to $d/5$, the system can be structured by use of a simple

control system.

[0047] As regards the target value to be applied, the response of the control system may be taken into account such that a value corresponding to response delay may be added to the value obtained through interpolation.

[0048] While in Figure 3 the wafer height measurement and the Z-position drive signal application in each step are performed at the same timing, the timing of Z-position drive signal application may be changed while taking the delay of driving system into account. Further, while in the illustrated example there is no drive in the wafer tilt direction (α or β), as a matter of course, the present invention is applicable also to measurement and drive with respect to such tilt direction.

[0049] On the other hand, application of the present invention is effective to solve a problem of degradation of line width precision due to abbe correction. Figure 4A shows motion of an X-stage in relation to abbe correction, wherein the axis of abscissa denotes time. The spacing between points a and k corresponds to the time required for a wafer to scan through the distance d between the center of exposure region and the wafer height detection system. The response speed of the stage is the time required for the wafer to move through a distance $d/2$. Points a, b, ..., and k represent the timing of sampling and rewriting of target value, for wafer and reticle stage interferometers. Z sampling and driving is performed only once during the period from a to k.

[0050] In Figure 4A, denoted at 50 is a read-out value of the interferometer in a case where there is no Z-axis drive. Inherently, it should be illustrated by a curve since the target value varies between points a and k. For convenience in explanation, however, it is illustrated with a constant target value between points a and k. If Z-axis drive is effected at timing of point f, the read-out value of the interferometer may shift as depicted at 51, by an amount corresponding to an abbe error. In order to correct this, the target value is corrected at timing of point h by an amount corresponding to the abbe error. Since however the amount of correction at 52 is large, deviation of the X stage from its target value becomes large, after point g, as depicted at 53.

[0051] Figure 4B shows motion of the X-stage in relation to the abbe correction, in a case where the present invention is applied. Z-axis drive is effected at timings of points a, c, e, g, i, and k. The target value for the interferometer is changed at points c, d, f, h, and j, in accordance with the drive amounts of a, c, e, g, i, and k, respectively. Final correction values for the interferometer, namely, those at 52 and 55, are of the same amount. However, since the target value for the stage (i.e., the correction value for the interferometer) is changed with intervals faster than the response speed of the X-stage and the correction is done frequently, stage vibration is not created and the deviation 56 from the target value is smaller than that at 53.

[0052] As described, when the present invention is

applied to a case where an abbe error produced by Z-position drive is to be corrected, it is possible to reduce the positional error in X direction, such that an exposure process of free from or with reduced variation in printed line width is enabled. Although the foregoing description has been made with respect to the X-stage which moves in the scan direction, the same applies to a Y stage. The abbe correction may be made with respect to the reticle stage side, not on the wafer stage side. However, in such occasion, the correction amount may increase in accordance with the magnification of the reduction projection lens.

[0053] An explanation will be given below of a method for manufacturing semiconductor devices by using the SOR exposure system described above.

[0054] Fig. 5 is a flowchart showing the sequence of the operation of manufacturing semiconductor devices (semiconductor chips, such as ICs or LSIs, liquid-crystal panels, or CCDs).

[0055] Referring to the flowchart shown in Fig. 5 in step 1 (circuit design), circuits of semiconductor devices are designed. In step 2 (manufacture of masks), masks having designed circuit patterns formed thereon are manufactured. In step 3 (manufacture of wafers), wafers are manufactured by using materials, such as silicon. Step 4 (wafer process) is called a pre-step, whereby actual circuits are formed on wafers by lithography technology by using the masks and wafers produced as described above. The subsequent step 5 (fabrication) is called a post step, whereby semiconductors are formed into chips by using the wafers manufactured in step 4. This step includes an assembly step (dicing, bonding), a packaging step (enclosing chips), and the like. In step 6 (inspection), inspection, for example, a test for confirming the operations of semiconductor devices manufactured in step 5, or a durability test, is performed. Semiconductor devices are completed through the processes described above and shipped (step 7).

[0056] Fig. 6 shows a detailed flowchart for the wafer process. In step 11 (oxidation), the surface of the wafer is oxidized. In step 12 (CVD), an insulating film is formed on the surface of the wafer. In step 13 (electrode - formation), electrodes are formed on the wafer by deposition. In step 14 (ion implantation), ions are implanted into the wafer. In step 15 (resist process, a photosensitizing agent is applied to the wafer. In step 16 (exposure), a circuit pattern of the mask is printed and exposed to the wafer by means of the SOR exposure system of the above-described embodiment. In step 17 (development), the exposed wafer is developed. In step 18 (etching), portions other than the developed resist image are etched. In step 19 (resist peel-off), resists which become unnecessary after etching is performed are removed. Circuit patterns are formed on the wafer in a multi-form by performing these steps repeatedly.

[0057] While the invention has been described with reference to the structures disclosed herein, it is not confined to the details set forth and this application is in-

tended to cover such modifications or changes as specified in the appended claims.

5 Claims

1. A surface position setting method for setting a surface position of a substrate, said method comprising:

a measuring step for measuring a surface position of the substrate surface at a measurement position, while relatively scanning the substrate surface relative to the measurement position;

a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at a predetermined position in a scan direction, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value;

a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and

a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related to those measurement positions before and after the particular location.

2. A method according to claim 1, wherein, in said determining step the target value in relation to the particular location is determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.
3. A method according to claim 2, wherein the interpolation comprises one of linear interpolation and multiple approximation interpolation.
4. A method according to any preceding claim, further comprising measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.
5. A scanning exposure method for printing a pattern of an original on to a substrate while relatively scanning the original and the substrate, said method comprising:

a measuring step for measuring a surface position of the surface of the substrate at a measurement position, while relatively scanning the substrate surface relative to the measurement position;

a driving step for setting a target value, when a predetermined location on the substrate having passed the measurement position is placed at an exposure position, on the basis of a measured value obtained in said measuring step, and for moving the substrate so that the surface position of the substrate is registered with the target value;

a setting step for setting a time interval for changing the target value in said driving step, to be shorter than a time interval of measurement in said measuring step; and

a determining step for determining a target value in relation to a particular location between different measurement positions on the substrate, on the basis of measured values related to those measurement positions before and after the particular location.

6. A method according to Claim 5, wherein, in said determining step, the target value in relation to the particular location is determined on the basis of interpolation of the measured values related to those measurement positions before and after the particular location.

7. A method according to Claim 6, wherein the interpolation comprises one of linear interpolation and multiple approximation interpolation.

8. A method according to any of claims 5 to 7, further comprising measuring a position of the substrate with respect to one of the scan direction and a direction perpendicular to the scan direction, performing a correction drive to move the substrate to a predetermined position, and setting a time interval for the correction drive to be shorter than the time interval for the surface position measurement.

9. A device manufacturing method comprising the scanning exposure method according to any one of claims 5 to 8, and the step of fabricating a device using the exposed substrate.

Patentansprüche

1. Verfahren zum Einstellen einer Oberflächenlage auf einem Substrat, mit den Verfahrensschritten:

einem Meßschritt zum Messen einer Oberflächenlage der Substratoberfläche an einer Meßstelle bei Abtasten der Substratoberfläche

relativ zur Meßstelle;

einem Ansteuerschritt zum Einstellen eines Zielwertes, wenn ein vorbestimmter Ort auf dem Substrat die Meßstelle passiert hat und sich an einer vorbestimmten Position in Abtastrichtung befindet, auf der Grundlage eines im Meßschritt gewonnenen Meßwertes und zum Bewegen des Substrates, so daß die Oberflächenlage des Substrats mit dem Zielwert registriert wird;

einem Einstellschritt zum Einstellen eines Zeitintervalls zum Ändern des Zielwertes im Ansteuerschritt auf einen kürzeren Wert als ein Zeitintervall der Messung im Meßschritt; und einem Bestimmungsschritt zum Bestimmen eines Zielwertes in Bezug auf einen speziellen Ort zwischen unterschiedlichen Meßstellen auf dem Substrat auf der Grundlage gemessener Werte bezüglich jener Meßstellen vor und nach dem speziellen Ort.

2. Verfahren nach Anspruch 1, bei dem der Bestimmungsschritt den Zielwert in Bezug auf den besonderen Ort auf der Grundlage einer Interpolation der gemessenen Werte bezogen auf jene Meßstellen vor und nach dem speziellen Ort bestimmt.

3. Verfahren nach Anspruch 2, bei dem die Interpolation eine Linearinterpolation und eine Mehrfachapproximationsinterpolation umfaßt.

4. Verfahren nach einem der vorstehenden Ansprüche, mit den weiteren Verfahrensschritten des Messens einer Position vom Substrat in Hinsicht auf entweder die Abtastrichtung oder eine Richtung senkrecht zur Abtasteinrichtung, des Ausführens einer Korrekturansteuerung, um das Substrat auf eine vorbestimmte Position zu bringen, und des Einstellens eines Zeitintervalls für die Korrekturansteuerung auf einen kürzeren Wert als das Zeitintervall für die Oberflächenlagemessung.

5. Abtastbelichtungsverfahren zum Drucken eines Musters eines Originals auf ein Substrat beim Abtasten des Originals relativ zum Substrat, mit den Verfahrensschritten:

einem Meßschritt zum Messen einer Oberflächenlage der Oberfläche vom Substrat an einer Meßstelle bei Abtastung der Substratoberfläche relativ zur Meßstelle;

einem Ansteuerschritt zum Einstellen eines Zielwertes auf der Grundlage eines im Meßschritt gewonnenen Meßwertes, wenn ein vorbestimmter Ort auf dem Substrat die Meßstelle passiert hat und an einer Belichtungsposition platziert ist, und zum Bewegen des Substrats so, daß die Oberflächenlage vom Sub-

- strat mit dem Zielwert registriert wird;
 einem Einstellschritt zum Einstellen eines Zeitintervalls zum Ändern eines Zielwertes im Ansteuerschritt auf einen kürzeren Wert als ein Zeitintervall der Messung im Meßschritt; und
 einem Bestimmungsschritt zum Bestimmen eines Zielwertes in Beziehung auf einen speziellen Ort zwischen unterschiedlichen Meßstellen auf dem Substrat auf der Grundlage gemessener Werte bezüglich jener Meßstellen vor und nach dem speziellen Ort.
6. Verfahren nach Anspruch 5, bei dem der Bestimmungsschritt den Zielwert in Beziehung auf den speziellen Ort auf der Grundlage einer Interpolation gemessener Werte bezogen auf jene Meßstellen vor und nach dem speziellen Ort bestimmt.
7. Verfahren nach Anspruch 6, bei dem die Interpolation eine Linearinterpolation und eine Mehrfachapproximationsinterpolation umfaßt.
8. Verfahren nach einem der Ansprüche 5 bis 7, mit den weiteren Verfahrensschritten des Messens einer Position vom Substrat in Hinsicht auf entweder die Abtastrichtung oder eine Richtung senkrecht zur Abtastrichtung, des Ausführens einer Korrekturansteuerung zum Bewegen des Substrats an eine vorbestimmte Position und des Einstellens eines Zeitintervalls für die Korrekturansteuerung auf einen kürzeren Wert als das Zeitintervall für die Oberflächenlagemessung.
9. Herstellverfahren, das das Abtastbelichtungsverfahren gemäß einem der Ansprüche 5 bis 8 und den Schritt der Herstellung einer Einrichtung unter Verwendung des belichteten Substrats umfaßt.
- Revendications**
1. Procédé d'établissement de position d'une surface pour établir la position d'une surface d'un substrat, ledit procédé comprenant :
- une étape de mesure pour mesurer une position de surface de la surface d'un substrat dans une position de mesure, tout en produisant un balayage relatif de la surface du substrat par rapport à la position de mesure ;
 une étape d'entraînement pour établir une valeur de consigne, lorsqu'un emplacement prédéterminé sur le substrat ayant passé par la position de mesure est placé dans une position prédéterminée dans une direction de balayage, sur la base d'une valeur mesurée obtenue dans ladite étape de mesure, et pour déplacer le substrat afin que la position de surface du substrat coïncide avec la valeur de consigne ;
 une étape d'établissement pour établir un intervalle de temps pour modifier la valeur de consigne dans ladite étape d'entraînement, afin qu'il soit plus court qu'un intervalle de temps de mesure dans ladite étape de mesure ; et
 une étape de détermination pour déterminer une valeur de consigne par rapport à un emplacement particulier entre différentes positions de mesure sur le substrat, sur la base de valeurs mesurées associées aux positions de mesure avant et après l'emplacement particulier.
2. Procédé selon la revendication 1, dans lequel, dans ladite étape de détermination, la valeur de consigne par rapport à l'emplacement particulier est déterminée sur la base d'une interpolation des valeurs mesurées associées aux positions de mesure avant et après l'emplacement particulier.
3. Procédé selon la revendication 2, dans lequel l'interpolation comprend une interpolation linéaire et une interpolation par approximations multiples.
4. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre une mesure d'une position du substrat par rapport à l'une de la direction de balayage et une direction perpendiculaire à la direction de balayage, l'exécution d'un entraînement de correction pour déplacer le substrat jusqu'à une position prédéterminée, et l'établissement d'un intervalle de temps pour l'entraînement pour la correction afin qu'il soit plus court que l'intervalle de temps pour la mesure de la position de surface.
5. Procédé d'exposition par balayage pour imprimer un motif d'un original sur un substrat tout en effectuant un balayage relatif de l'original et du substrat, ledit procédé comprenant :
- une étape de mesure pour mesurer une position de surface de la surface du substrat dans une position de mesure, tout en réalisant un balayage relatif de la surface du substrat par rapport à la position de mesure ;
 une étape d'entraînement pour établir une valeur de consigne, lorsqu'un emplacement prédéterminé sur le substrat ayant passé la position de mesure est placé dans une position d'exposition, sur la base d'une valeur mesurée obtenue dans ladite étape de mesure, et pour déplacer le substrat afin que la position de surface du substrat coïncide avec la valeur de consigne ;
 une étape d'établissement pour établir un intervalle de temps pour modifier la valeur de consigne dans ladite étape d'entraînement, afin qu'il soit plus court qu'un intervalle de temps de mesure dans ladite étape de mesure ; et
 une étape de détermination pour déterminer une valeur de consigne par rapport à un emplacement particulier entre différentes positions de mesure sur le substrat, sur la base de valeurs mesurées associées aux positions de mesure avant et après l'emplacement particulier.

qu'il soit plus court que l'intervalle de temps de mesure dans ladite étape de mesure ; et une étape de détermination pour déterminer une valeur de consigne par rapport à un emplacement particulier entre les différentes positions de mesure sur le substrat, sur la base de valeurs mesurées associées aux positions de mesure avant et après l'emplacement particulier.

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6. Procédé selon la revendication 5, dans lequel, dans ladite étape de détermination, la valeur de consigne par rapport à l'emplacement particulier est déterminée sur la base d'une interpolation des valeurs mesurées par rapport aux positions de mesure avant et après l'emplacement particulier. 15
7. Procédé selon la revendication 6, dans lequel l'interpolation comprend une interpolation linéaire et une interpolation par approximations multiples 20
8. Procédé selon l'une quelconque des revendications 5 à 7, comprenant en outre une mesure d'une position du substrat par rapport à l'une de la direction de balayage et une direction perpendiculaire à la direction de balayage, l'exécution d'un entraînement de correction pour déplacer le substrat jusqu'à une position prédéterminée, et l'établissement d'un intervalle de temps pour l'entraînement de correction afin qu'il soit plus court que l'intervalle de temps pour la mesure de la position de surface. 25 30
9. Procédé de fabrication de dispositifs comprenant le procédé d'exposition par balayage selon l'une quelconque des revendications 5 à 8, et l'étape de fabrication d'un dispositif utilisant le substrat exposé. 35

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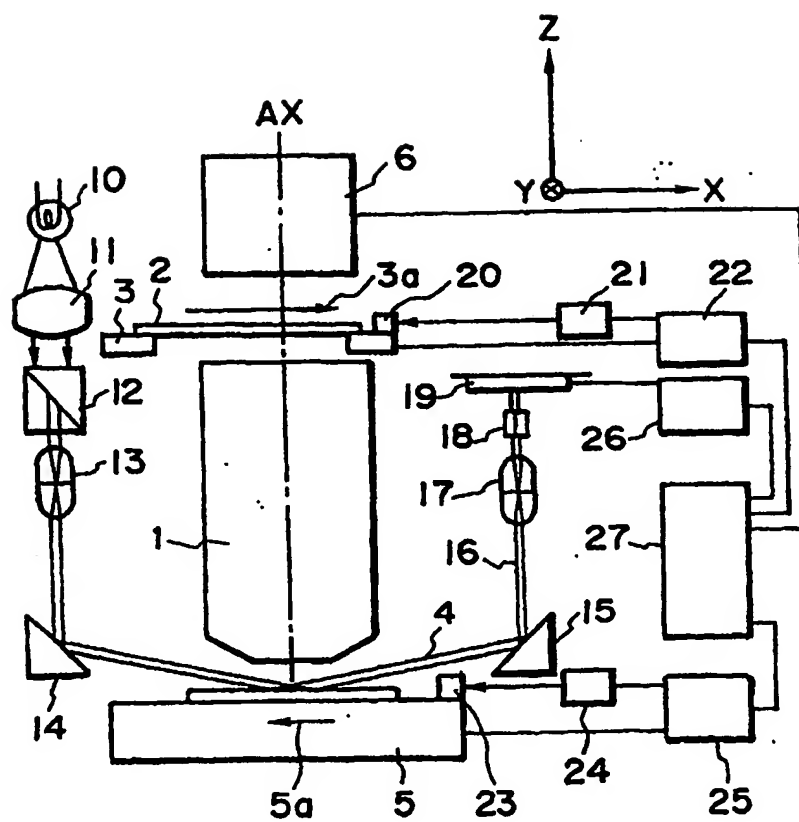


FIG. 1

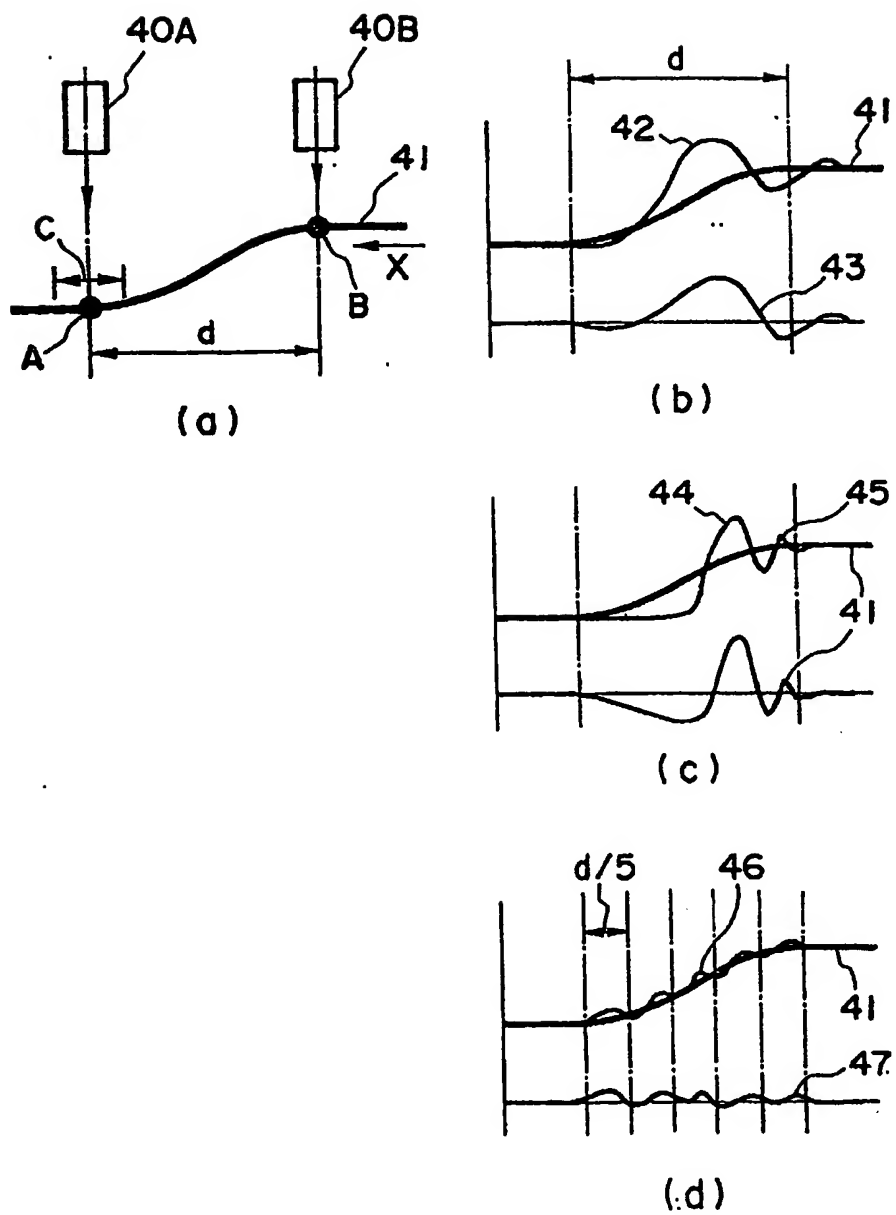


FIG. 2

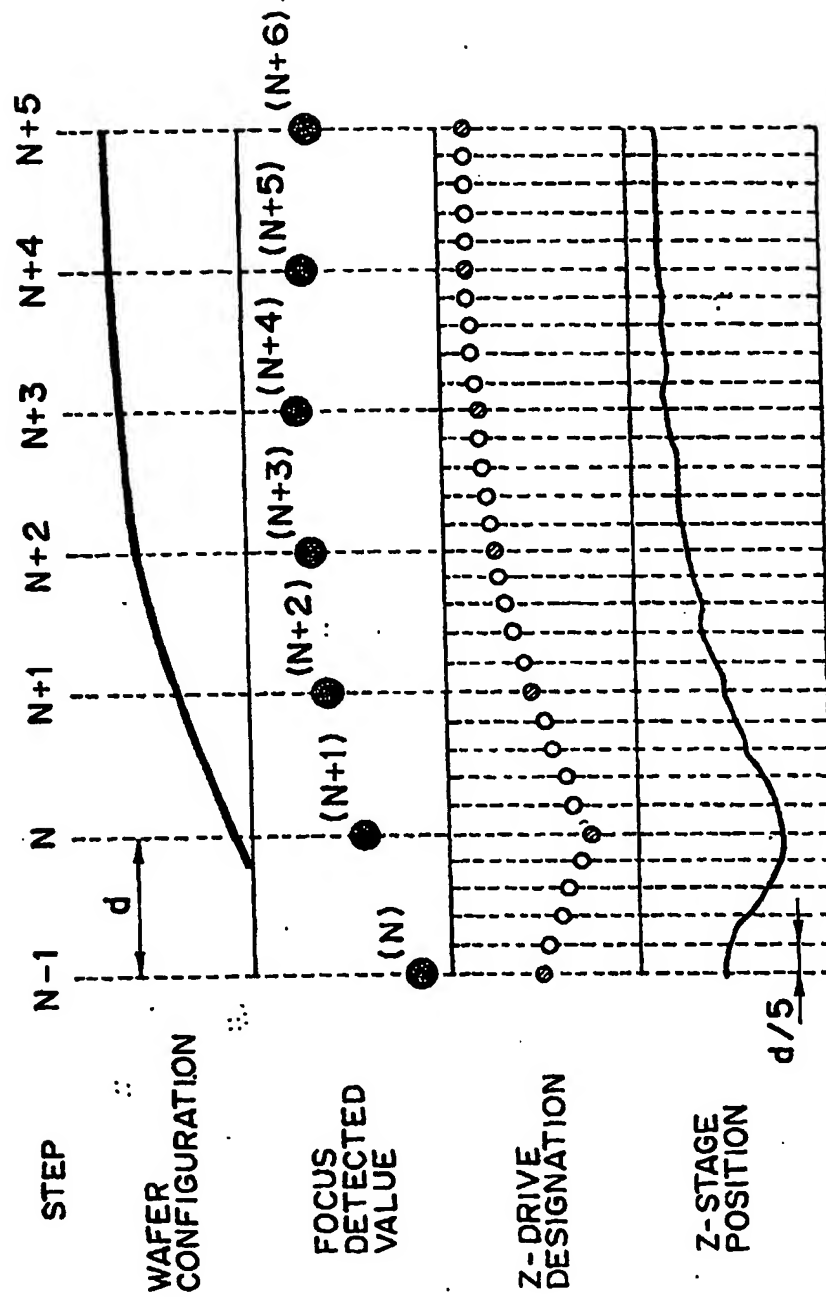


FIG. 3

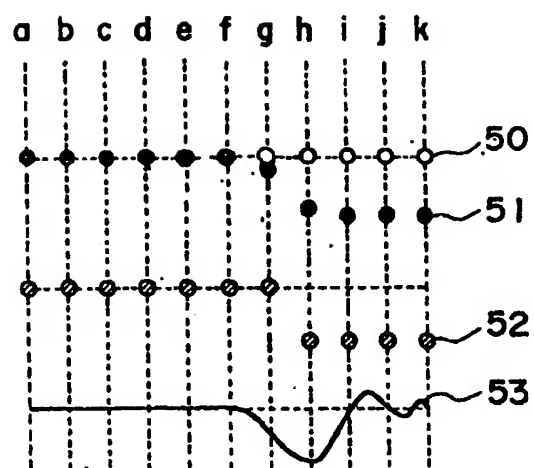


FIG. 4A

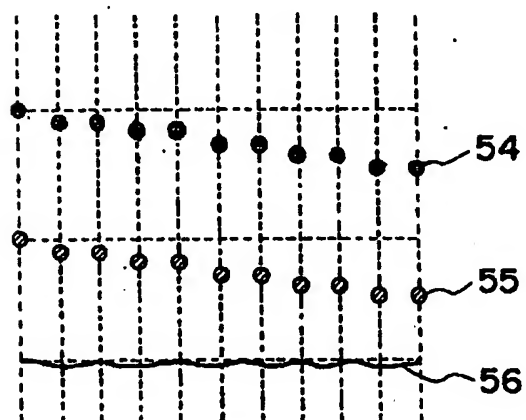
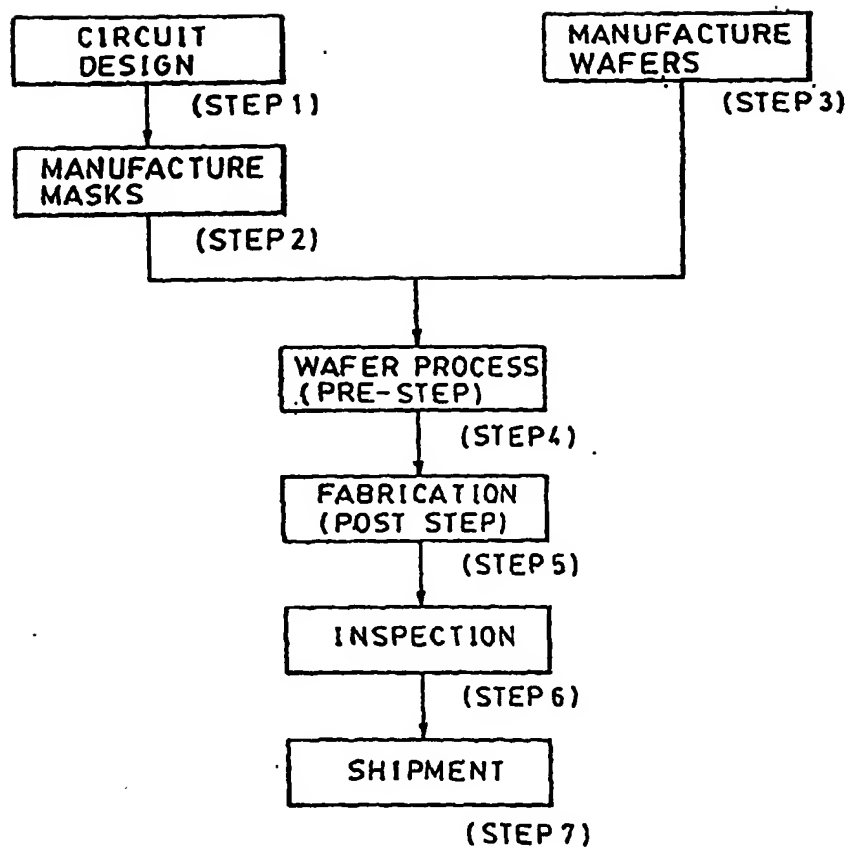


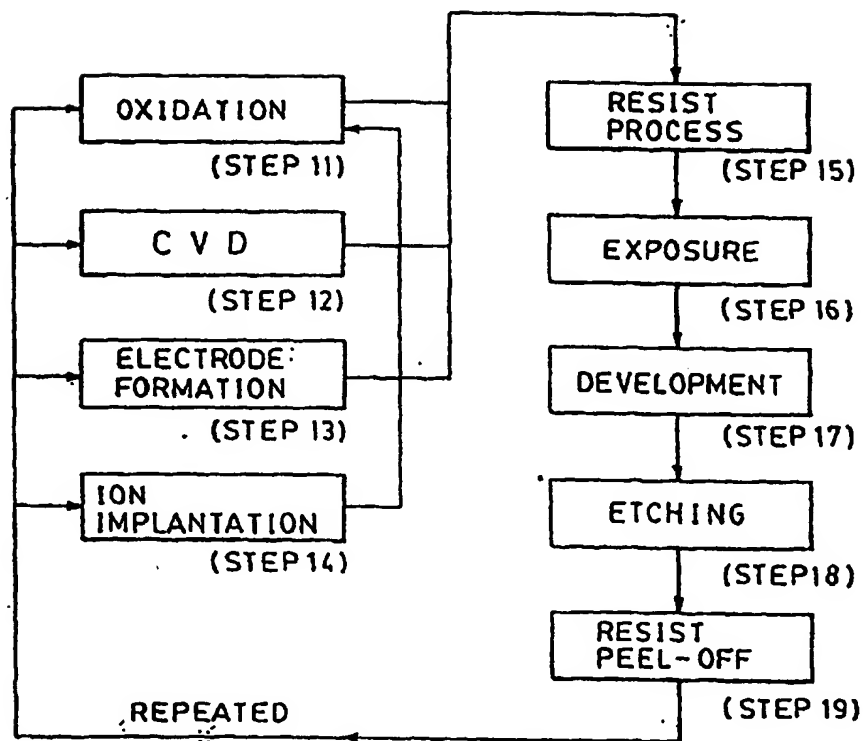
FIG. 4B

FIG. 5



**FLOW FOR MANUFACTURING
SEMICONDUCTOR DEVICES**

FIG. 6



WAFER PROCESS